

K. Jeyapalan, W. Yao, D. Bhagawati, J. Bovinett, V. J. Sumangali

Soft Photogrammetry for Highway Engineering

Final Report

February 1998

Sponsored by the
Iowa Department of Transportation
and the Iowa Highway Research Board

Iowa DOT Project HR-387
ISU-ERI-Ames-98131



**Iowa Department
of Transportation**

report

**College of
Engineering
Iowa State University**

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Iowa Department of Transportation.

K. Jeyapalan, W. Yao, D. Bhagawati, J. Bovinett, V. J. Sumangali

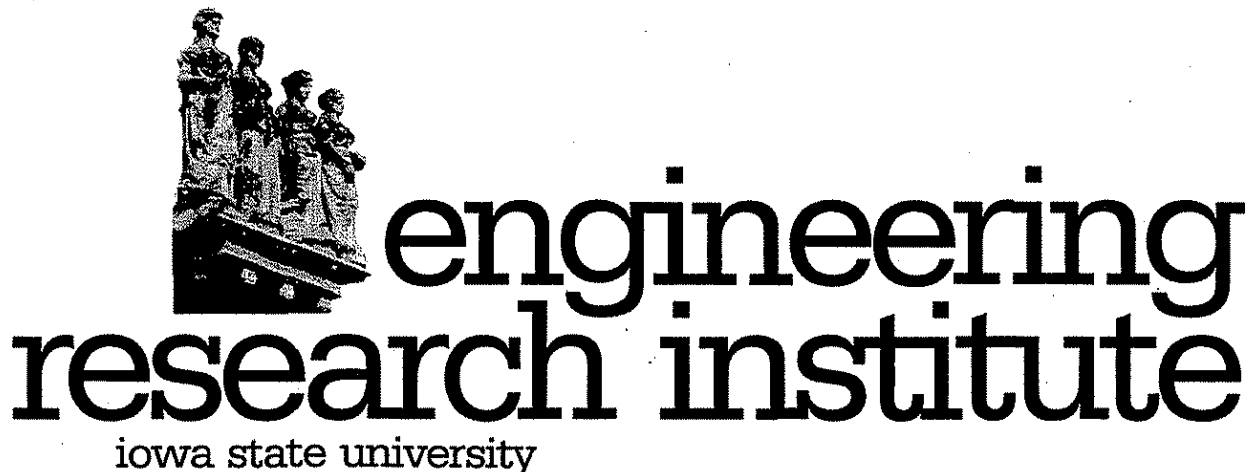
Soft Photogrammetry for Highway Engineering

Final Report

February 1998

Sponsored by the
Iowa Department of Transportation
and the Iowa Highway Research Board

Iowa DOT Project HR-387
ISU-ERI-Ames-98131



CONTENTS

Executive Summary.....	vi
Chapter 1. Introduction.....	1-1
Chapter 2. Soft Photogrammetry and Related Software.....	2-1
2.1. Soft Photogrammetry and GIS.....	2-8
2.2. SoftPlotter.....	2-9
Chapter 3. Campus Project.....	3-1
3.1. Accuracy of Photo Coordinates.....	3-1
3.2. Accuracy of Aerial Triangulation by Soft Photogrammetry.....	3-4
3.3. Accuracy of Auto Correlation by Soft Photogrammetry.....	3-7
3.4. Accuracy of SoftPlotter Compared to a First-order Stereo Plotter Zeiss C8.....	3-12
3.5. Accuracy of Planimetry and Orthophoto by SoftPlotter.....	3-16
Chapter 4. Highway 218 Project.....	4-1
4.1. Aerial Triangulation.....	4-1
4.2. Creation of TIN.....	4-12
4.3. Creation of Orthophotos and Mosaicing.....	4-17
4.4. Digitizing Tool: KDMS.....	4-18
4.5. GIS Application and Map Making.....	4-19
4.6. Feasibility of Transferring the Technology.....	4-21
Chapter 5. Future Applications of Soft Photogrammetry.....	5-1
5.1. Helicopter Project.....	5-1
5.2. Video Logging Images for As-built Survey and Monitoring Road Conditions.....	5-7
5.3. Integration of Soft Photogrammetry and Virtual Reality.....	5-11
Chapter 6. Conclusion and Recommendation.....	6-1

CONTENTS (Cont'd)

7. Acknowledgment.....	7-1
8. Bibliography.....	8-1
9. Appendixes	
A. Hardware.....	A-1
B. Software.....	B-1
C. Comparison of Software.....	C-1
Integraph and SoftPlotter.....	C-2
Socket and SoftPlotter.....	C-13
TNTMips and SoftPlotter.....	C-21
D. Transfer of Technology.....	D-1
Letter from county engineer.....	D-2
Letter from photogrammetrist using analytical plotter.....	D-3
Letter from photogrammetrist using analogue plotter.....	D-4

LIST OF FIGURES

2.1	Process of Photography	2-1
2.2	Geometry of Camera System	2-2
2.3	Flat bed scanner.....	2-3
2.4	Window Display.....	2-3
2.5	Exterior Orientation of a Stereo Pair.....	2-3
2.6	Flight Planning.....	2-4
2.7	Stereo Matching.....	2-5
2.8	Projection Geometry.....	2-5
2.9	Epi-polar Geometry.....	2-5
2.10	Stereo Viewing.....	2-6
2.11	Window Size.....	2-7
2.12	Error in Exterior Orientation Parameters.....	2-7
2.13	The GIS concept.....	2-8
2.14	SoftPlotter Primary Menu.....	2-9
3.1	RMS vs. Pixel Size for HP ScanJet 3C.....	3-2
3.2	RMS vs. Pixel Size for HP ScanJet 4C.....	3-2
3.3	Contours from Kelsh, C.I. = 2 meters.....	3-10
3.4	Contours from SoftPlotter, C.I. = 2 meters.....	3-10
3.5	Difference Contours for SoftPlotter-Kelsh, C.I. = 2 meters.....	3-10
3.6	Surface from Kelsh.....	3-11
3.7	Surface from SoftPlotter.....	3-11
3.8	Difference Surface for SoftPlotter-Kelsh.....	3-12
3.9	Campus Map from SoftPlotter.....	3-17
3.10	Campus Map from Kelsh.....	3-17
3.11	Campus Map Comparison between SoftPlotter and Kelsh.....	3-17
3.12	Campus Orthophoto.....	3-19
3.13	Campus Map Overlay – Planimetric Features from Kelsh and Orthophoto from SoftPlotter.....	3-19
3.14	Iowa State University Buildings and Roads.....	3-22
3.15	Iowa State University Buildings and Roads.....	3-22
3.16	Iowa State University Buildings and Roads.....	3-22

LIST OF FIGURES (Cont'd)

4.1	RMS Vs. Photograph for Interior Orientation.....	4-2
4.2	Surface Of Merged TIN.....	4-14
4.3	1 M contour interval Merged TIN.....	4-15
4.4	Contour Comparison.....	4-16
4.5	Contour Comparison.....	4-16
4.6	Orthophoto from Model 154/155.....	4-17
4.7	Orthophoto from Model 155/156.....	4-17
4.8	Mosaicing of the Three Models.....	4-18
4.9	Comparison of SoftPlotter with Kern PG2.....	4-19
4.10	Map Made with ArcView.....	4-20
5.1	Control and Pass Points for Strip of Six Photos (209 to 214)	5-2
5.2	Ground Surface of the Two Models.....	5-4
5.3	Orthophoto.....	5-5
5.4	Edited Orthophoto.....	5-6
5.5	Van with Video Camera and GPS Receiver.....	5-7
5.6	Calibration Targets for Video Camera.....	5-7
5.7	Video Imagery of Secondary Road.....	5-7
5.8	Plotted Details from SoftPlotter Measurements of Videologging Imagery	5-7
5.9	Area of Interest in the Original Image.....	5-8
5.10	Unsupervised Classification after Edge Enhancement.....	5-8
5.11	Original Imagery.....	5-8
5.12	Surface from SoftPlotter.....	5-11
5.13	Iowa State University Buildings and Roads.....	5-11
5.14	SoftPlotter™ on Silicon Graphics Workstation.....	5-12
5.15	The world of Virtual Reality.....	5-12
5.16	A Virtual Reality Environment.....	5-13

LIST OF TABLES

3.1	Comparison of Photo Photo Coordinates between SoftPlotter and Comparator...	3-3
3.2	Comparison of Triangulation Results Using Three Different Software Packages	3-5
3.2.1	Comparison of Triangulation between SoftPlotter and Albany.....	3-6
3.3	Comparison of Data Points Outside Three Standard Deviations.....	3-8
3.4	Difference between Kelsh and SoftPlotter Z Coordinate values.....	3-9
3.5	Ground Coordinates from Ziess C8 Model Coordinates.....	3-15
3.6	Statistical Analysis of the Comparison.....	3-18
3.7	Comparison of SoftPlotter and Kelsh.....	3-20
3.8	Attribute Data of Campus.....	3-23
3.9	Attribute Data of Campus2.....	3-24
3.10	Attribute Data of Contour1.....	3-24
4.1	Ground Controls in the Strip.....	4-1
4.2	Triangulation Results.....	4-4
4.3	Coordinates of Control and Pass Points after Triangulation.....	4-4
4.4	Improved Triangulation Results.....	4-8
4.5	Coordinates of Ground Points from Improved Triangulation.....	4-8
4.6	RMS of the Difference.....	4-12
5.1	Control Point Coordinates from SoftPlotter and Albany.....	5-3
5.2	Calibration of Video Cameras.....	5-9

EXECUTIVE SUMMARY

The SoftPlotter, a soft photogrammetric software and Silicon Graphics workstation, was used to evaluate the accuracy of soft photogrammetry and identify applications of this technology to highway engineering.

A comparative study showed that SoftPlotter compares well with other software such as Socket and Integraph. The PC software TNT mips is inexpensive but needs further development to be comparable to SoftPlotter.

The Campus Project showed that soft photogrammetry is accurate for traditional photogrammetric applications. It is also accurate for producing orthophoto and base maps for Geographic Information Systems (GISs).

The Highway Project showed that soft photogrammetry is accurate for highway engineering and that the technical staff at the Iowa Department of Transportation (IA DOT) can be easily trained in this new technology.

The research demonstrated that soft photogrammetry can be used with low-flight helicopter photography for large-scale mapping in highway engineering. The researchers recommend that research be conducted to test the use of digital cameras instead of the traditional aerial cameras in helicopter photography.

Research that examines the use of soft photogrammetry with video logging imagery for inventory and GIS studies in highway maintenance is also recommended.

Research is also warranted into the integration of soft photogrammetry with virtual reality, which can be used in three-dimensional designing and visualization of highways and subdivisions in real time.

The IA DOT owns one analytical plotter and two analogue plotters. The analytical plotter is used for aerial triangulation, and the analogue plotters are used for plotting. However, neither is capable of producing orthophotos. Therefore, the researchers recommend that the IA DOT purchase soft photogrammetric workstations for orthophoto production, and if and when required, use it for aerial triangulation and plotting. In the future, the analogue plotters may become obsolete. At that time, the researchers recommend that the analogue plotters be phased out and replaced by soft photogrammetric workstations.

CHAPTER 1. INTRODUCTION

A highway engineering project involves planning, preliminary survey, design, location survey, construction, and maintenance. Topographic (topo) maps, aerial and satellite photography are used to plan the project. Plan, profile, cross-section, and large-scale topo maps produced by the preliminary survey are used in the design work. Its maintenance requires an "as -built" survey and field inspection.

Topographic maps and cross sections for highway applications are now produced by photogrammetry. Highways are designed on plan, profile, and cross-section maps, and the as-built survey is done by field inspection, using this design map. For highway engineering, photogrammetry uses large-scale photographs (1 inch = 250 ft to 1 inch = 500 ft) to produce 1 inch = 50 ft and 1 inch = 100 ft topo maps showing 2 ft to 5 ft contours and cross sections. Photographs are obtained by precise metric aerial cameras. These photos are used in analogue and analytical stereoplotters to produce topographic maps and cross sections.

With the advent of computer and electronic technology, conventional photography can be replaced by video imaging technology. In this technology, the film is replaced by equally spaced detectors on the film plane. Each detector produces a response signal, known as a radiometric value, that is proportional to the light received from the corresponding element of the object being photographed. When projected on the TV or computer screen, this signal produces the image of the object. Unfortunately, due to the lack of geometric properties, many of these video images cannot be used in photogrammetry. However, the film from aerial cameras can be scanned electronically to produce the radiometric values at equal intervals. Each interval is known as the pixel size. The quality of the scanners and the video depend on the accurate positioning of the detectors on the image plane and the accuracy of response of the detector. The position of the pixel and analytical photogrammetric principles can be used to determine the space location of the object. The feature classification of the object can be obtained by using the radiometric values and the remote sensing principles. The technology, which uses the position and radiometric values of the pixel to determine the spatial location of an object and identify it, is known as "soft photogrammetry." Theoretically,

soft photogrammetry can be used to produce topo maps, cross section, and/or digital elevation models (DEM) automatically in digital or soft copy. These soft copies can then be used as the base maps in Geographic Information System (GIS) and Computer Aided Design (CAD). Surveyors, planners, and design engineers can add attribute data on the GIS base map for project management. Engineers can use the CAD base maps for designing a highway. The CAD files created by soft photogrammetry contain three-dimensional (3-D) information. Soft photogrammetry also produces 3-D stereo images on the computer screen. Design engineers, planners, and the general public can use soft photogrammetry to view, in 3-D, the effect and the accuracy of the design on the computer screen before the highway is constructed.

Video logging is currently used in highway maintenance. Soft photogrammetry can use these videologging images to produce an as-built survey map and to identify and locate areas having maintenance problems. The as-built survey map can also be used to check the accuracy of construction, note vandalism, and collect inventory data. Location and identification of problem areas are invaluable for managing and maintaining a safe highway.

During the last 30 years, soft photogrammetry (U.V. Helava, 66, Pertl Alfred 1986) has replaced analogue and analytical photogrammetry. Autometric, Leica, Intergraph, and Zeiss have developed software for such workstations as Silicon Graphics, Sun, and Integraph, which have fast processors (200 Hz) and large storage capabilities. This software can be used for the usual photogrammetric applications such as aerial triangulation, orthophoto, stereoplottting, and DEM. Further, this software can be used for producing the digital base maps used in GIS, CAD, and remote sensing. Unlike in analytical photogrammetry, the software and hardware in soft photogrammetry can be used with simple modification in terrestrial photogrammetric work (video logging in highways), and close range photogrammetry (in medicine).

The objectives of this study are to:

- (1) study the SoftPlotter software developed by Vision International and compare it with other software such as Socket, Integraph, and TNTMips.

- (2) check the accuracy of soft photogrammetry for aerial triangulation, stereoplotting, DEM, contours and base maps for GIS, based on the Campus Project.
- (3) check the accuracy of soft photogrammetry for highway application and describe the problems of technology transfer based on the Highway 218 Project.
- (4) describe special applications of soft photogrammetry for highway engineering using video logging imagery, helicopter photographs, and virtual reality.
- (5) give the conclusion and make recommendations

The Campus Project shows that soft photogrammetry works well for aerial triangulation, stereoplotting, contouring, and creating base maps for GIS. On the basis of the Highway 218 Project, the researchers concluded that soft photogrammetry produces accurate results in highway engineering applications. Additionally, personnel can be easily trained in this new technology. The Helicopter Project demonstrates that soft photogrammetry can be adopted for large-scale mapping using low-flying helicopter photographs. The use of soft photogrammetry with video logging imagery and virtual reality is also promising. The researchers recommend that further research be conducted to investigate the use of soft photogrammetry with video logging for highway inventory. The researchers also recommend that research be done in integrating soft photogrammetry and virtual reality.

CHAPTER 2. SOFT PHOTOGRAMMETRY AND RELATED SOFTWARE

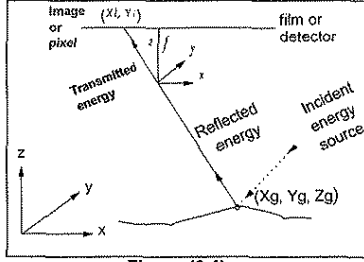


Figure (2.1)

Process of Photography

Photogrammetry is the art and science of making measurements on photographs. A photograph is the image of objects formed by light reflected by the objects and transmitted through the lens on silver halide emulsion film. The halide emulsion consists of 20- μm particles that react to the photon energy of the light and precipitate silver halide, depending on the amount of this energy. The “texture” and “tone” of the

image is used to identify the object. The location of the object (X_g, Y_g, Z_g) in a ground coordinate system (X, Y, Z) is determined from:

$$x_i = -f \frac{a_{11}(x_g - x_0) + a_{12}(y_g - y_0) + a_{13}(z_g - z_0)}{a_{31}(x_g - x_0) + a_{32}(y_g - y_0) + a_{33}(z_g - z_0)} \quad (1)$$

$$y_i = -f \frac{a_{21}(x_g - x_0) + a_{22}(y_g - y_0) + a_{23}(z_g - z_0)}{a_{31}(x_g - x_0) + a_{32}(y_g - y_0) + a_{33}(z_g - z_0)} \quad (2)$$

where (x_i, y_i, f) are the image coordinates in the photo coordinate system (x, y, z). (X_0, Y_0, Z_0) are the nodal point coordinates in the ground coordinate system. “ f ” is the principal distance, which is the perpendicular distance from the nodal point to the film plane. The parameters (a_{11}, \dots, a_{33}) are the elements of the rotation matrix that rotates the photo coordinate system parallel to the ground coordinate system and are given by

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} = \begin{bmatrix} \cos \kappa & -\sin \kappa & 0 \\ \sin \kappa & \cos \kappa & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos \phi & 0 & \sin \phi \\ 0 & 1 & 0 \\ -\sin \phi & 0 & \cos \phi \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \omega & -\sin \omega \\ 0 & +\sin \omega & \cos \omega \end{bmatrix}$$

where ω is the primary rotation about the x axis, ϕ is the secondary rotation about the y axis, and κ is the tertiary rotation about the z axis. See Figure 2.1.

Photogrammetry determines the ground coordinates of any point in the image. The first step is to determine the photo coordinates of the image point. This is determined by calibrating the camera. The calibration of the camera determines the principal distance,

location of the principal point, and the lens distortion at any point. The primary and secondary axis are

Geometry of Camera system

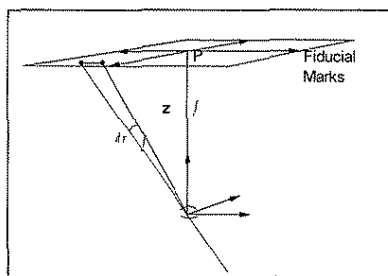


Figure (2.2)

defined by fiducial marks in the film plane. When the coordinates of the fiducial marks in the x, y system are known, the photo coordinates are determined by measuring the film coordinates or pixel coordinates of the image points and the fiducial marks. See Figure 2.2. In analogue photogrammetry, the photo coordinates are determined manually by orienting the

fiducial marks on the film with that of the projector. In analytical photogrammetry, the film coordinates are measured by a stereo comparator. A stereo comparator is a special, optical mechanical instrument that measures x, y coordinates to ± 1 micron. However, in soft photogrammetry the pixel coordinates are measured on the computer screen by placing the cursor on the image point. The selected image area can be displayed by zooming in and out, and the cursor can be placed on the image point. The film is scanned by a scanner consisting of electronic detectors that record the signal strength of the light transmitted through an area of the film corresponding to the area of the detector known as pixel size. A scanner consists of an array of detectors. There are drum and flatbed scanners. In the flatbed, the detector moves in both x and y directions, while in the drum scanner, the drum rotates the film and the detector moves along the axis of the drum. See Figure 2.3. Though faster, the drum scanner is generally less accurate than the flatbed. The accuracy of the pixel coordinate depends on the display resolution and on the size of the pixel and cursor.

Flat bed Scanner

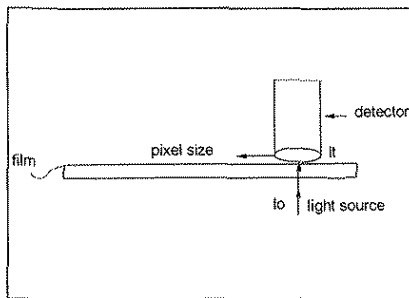


Figure (2.3)

Window Display

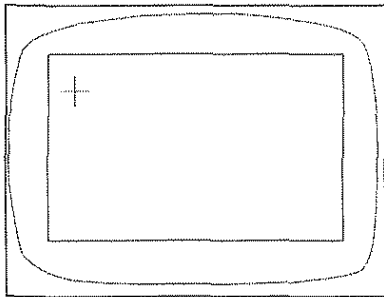


Figure (2.4)

See Figure 2.4. Using conventional photography, the comparator will give the most accurate photo coordinates. However, soft photogrammetry is most suitable to process digital or video camera imagery.

The second step is to determine the exterior orientation parameters X_0 , Y_0 , Z_0 , κ , ϕ , and ω . This is done by selecting or pre-marking at least three points that can be identified on the photo, then determining their ground coordinates by ground survey method, and finally measuring their photo coordinates. In both soft and analytical photogrammetry, the parameters are determined using Equation 1 and 2 and the method of least squares. However in

analogue photogrammetry a stereo plotter is used. From Equation 1 and 2, it is obvious that knowing the exterior orientation parameters and the photo coordinates, to determine the ground coordinate three

Exterior Orientation of a Stereo Pair

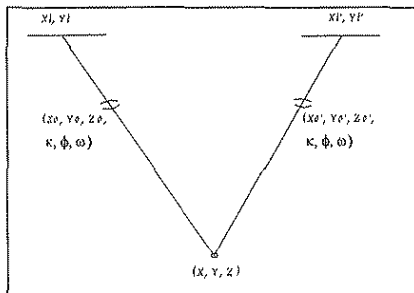


Figure (2.5)

equations are needed instead of two equations (1 and 2).

Therefore a stereo pair of imagery is used where photo coordinates (x_i, y_i) and (x'_i, y'_i) from the two photos of the same ground point will generate four equations to calculate the ground coordinates (X, Y, Z) .

See Figure 2.5. In analogue photogrammetry, the 12 exterior orientation parameters $(X_0, Y_0, Z_0, \kappa, \phi, \omega; X'_0, Y'_0, Z'_0, \kappa', \phi', \omega')$ of the stereo pair, Figure 2.5., are determined in the following four steps: (1) by relative orientation, five elements, typically $B_y = Y'_0 - Y_0$, $B_z = Z'_0 - Z_0$, $\Delta\kappa = \kappa - \kappa'$, $\Delta\phi = \phi - \phi'$, and $\Delta\omega = \omega - \omega'$ are determined; (2) using these five elements, the pair is combined to create a stereo model, which can be viewed in stereo; (3) by scaling the element, $B_x = x'_i - x_i$ is determined; and (4) by leveling, ϕ and ω are determined. In the final step of orientation, κ is

determined. Ground controls by ground survey methods are expensive and time consuming.

Alternatively, they are determined by the process of aerial or photo triangulation. In aerial triangulation, photographs are taken at different scales to meet the required project mapping scale.

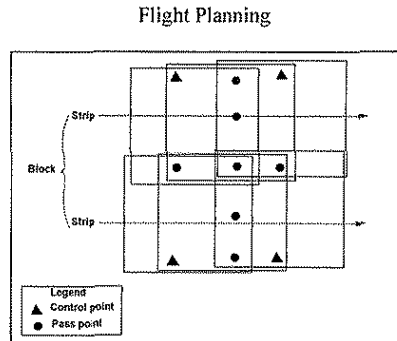


Figure (2.6)

Depending on the project size and scale of the photography, strips of photographs are obtained such that adjacent photographs have 50% to 60% overlap and adjacent strips have 20% to 50% overlap. See Figure 2.6.

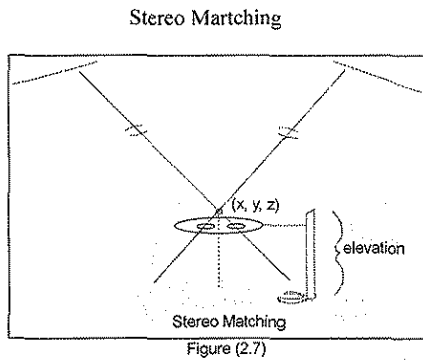
Thus the ground control points required to determine the exterior orientation parameters are minimized. Using only a minimum of three to four ground control points, it is possible to determine the ground coordinates of points that are common to two models or two strips. The common points are known as pass points. In analytical and soft photogrammetry, the coordinates are determined by a simultaneous least-square procedure in which the photo coordinates of all pass and ground control points are processed simultaneously to give the exterior orientation parameters. However, in analogue photogrammetry where the models are formed by relative orientation, the models are joined to form a strip by three-dimensional transformation, and the strips are joined to form a block. The block coordinates (x_m, y_m, z_m) are then transformed to ground coordinates using

$$\begin{bmatrix} x_g \\ y_g \\ z_g \end{bmatrix} = R \begin{bmatrix} x_m \\ y_m \\ z_m \end{bmatrix} + \begin{bmatrix} x_T \\ y_T \\ z_T \end{bmatrix}$$

where R is an orthogonal matrix and (X_T, Y_T, Z_T) are the translation elements. The matrix R , which is a function of κ, ϕ , and ω , and the three translation elements are determined by using three or more control points. Mechanically, the models and strip are joined by scaling and leveling.

The third step is to determine the spatial coordinate (x_g, y_g, z_g) of any point in the overlap area. In analogue photogrammetry, once the exterior orientation parameters are determined, the projectors containing the film are oriented accurately and the rays from a corresponding area of adjoining photographs are projected and viewed by the left and right eye simultaneously to give a stereoscopic effect. See Figure 2.7. The observer matches the identical image in stereo and determines the coordinates manually.

In analytical photogrammetry, the observer views the rectified images instead of the projected

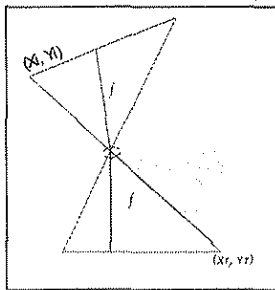


images. The rectified image (x_r, y_r) for a given image (x_i, y_i) is given by

$$x_r = -f \frac{a'_{11}(x_i) + a'_{12}y_i + a'_{13}f}{a'_{31}(x_i) + a'_{32}y_i + a'_{33}f} \quad (3)$$

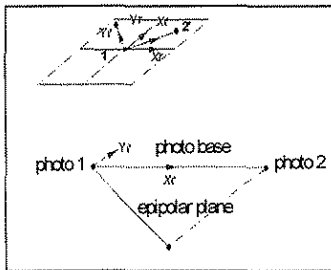
$$y_r = -f \frac{a'_{21}(x_i) + a'_{22}y_i + a'_{23}f}{a'_{31}(x_i) + a'_{32}y_i + a'_{33}f} \quad (4)$$

Projection Geometry



where $A' = A^T$. See Figure 2.8. The observer matches the identical image in stereo and the coordinates (x_g, y_g, z_g) are determined by computer software using Equation 1 and 2.

Epi-polar Geometry



In soft photogrammetry, the coordinates are transformed to epipolar coordinates (x_e, y_e) so that the x-axis is in the direction of the photo base of the stereo pair. See Figure 2.9.

This gives the observer the view in the epipolar plane even though the images are displayed on the computer screen.

The (x_e, y_e)

$$\begin{pmatrix} x_e \\ y_e \end{pmatrix} = \begin{pmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{pmatrix} \begin{pmatrix} x_r \\ y_r \end{pmatrix} \text{ and } \tan \theta = \left(\frac{x_1^0 - x_2^0}{y_1^0 - y_2^0} \right) \quad (5)$$

where (x_1^0, y_1^0, z_1^0) and (x_2^0, y_2^0, z_2^0) are the nodal point coordinates of camera 1 and camera 2 in the ground coordinate system, assuming $Z_0 \equiv Z'_0$. In aerial photogrammetry $Z_0 \equiv Z'_0$ but in terrestrial photogrammetry this is not true. In this case, the second photo must be scaled by $\left(\frac{Z_0}{Z'_0} \right) (x'_e, y'_e)$.

The images of the right and left photographs are displayed alternately on the screen while the observer looks through a synchronized stereo emitter glass to get the stereo view. Typically, the images are alternated every 1/60th of a second. See Figure 2.10.

The fourth step is to produce the planimetric and contour map. In both analogue and analytical photogrammetry, data for these maps are manually collected in digital form by the operator and then displayed using CAD computer software. However, in soft photogrammetry these functions can be performed both manually and automatically.

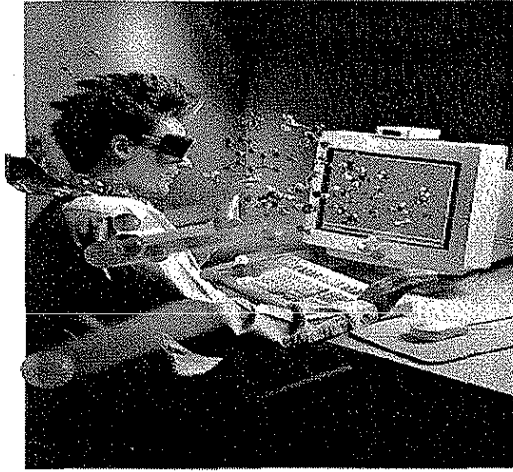
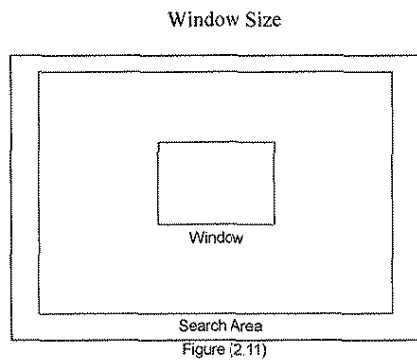


Fig 2.10 Stereo Viewing

When done automatically, the process is called "image matching." In image matching, the objective is to identify and locate the conjugate pixel, (x'_e, y'_e) . In the second photo, this corresponds to a pixel (x_e, y_e) of the first photo using the gray scale $g(x_e, y_e)$ or the radiometric values at the pixels and the cross-correlation equation

$$c(i, j) = \frac{\sum_{x=x_2}^{x=x_1} \sum_{y=y_0}^{y=y_1} g_1(x_e, y_e) * g_2(x'_e - i, y'_e - j)}{\sum_{x=x_2}^{x=x_1} \sum_{y=y_0}^{y=y_1} g_1^2(x_e, y_e) \sum_{x=x_2}^{x=x_1} \sum_{y=y_0}^{y=y_1} g_2^2(x'_e - i, y'_e - j)}$$

where $(y_j - y_0 + 1)$ and $(x_1 - x_0 + 1)$ define the window size or the image size of the object to be identified,



and the limits of i, j are defined by the search range. See Figure 2.11.

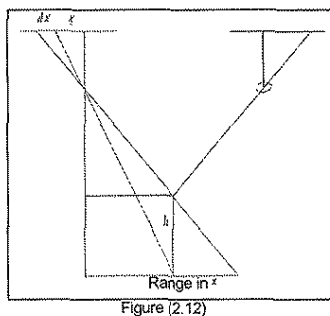
Given (x_e, y_e) , the (x'_e, y'_e) can be calculated for an estimated elevation such as average ground elevation using Equation 3 and 4.

The range of (x'_e, y'_e) is then limited to the expected variation in elevation and the error in determining the exterior orientation

parameters. The location is given by $(x'_e - i, x'_e - j)$, which gives the maximum correlation c_{ij} . According to basic photogrammetric principles, the range of y'_e will depend on the error in the exterior orientation parameters, and the range of x'_e will depend on the variation in the elevation. Assuming an error (σ) of 2 pixels due to errors in exterior orientation parameters, the range in

y_e is $(-3\sigma \text{ to } +3\sigma)$, which is -6 to 6 pixels. The range in x_e is given by $\frac{x}{H}dh$; if $\frac{dh}{H} = 0.10$ or 10% and

Error in Exterior Orientation Parameters



$x_e = 200$ pixels

then the range is -20 to 20 pixels. See Figure 2.12.

In planimetric mapping, the window size will depend on the feature, the scale, and the location, etc. The automatic planimetric mapping is being developed, and this technology should be available in the near future.

Contours are drawn by software such as Surfer, which uses elevations at a number of points in the area to interpolate the contours. The points (x_g, y_g) with known elevation z_g , are known as DTM or DEM points. Typically, DEM are collected at even spacing. In the automatic creation of DEM by soft photogrammetry, the window size will depend only on the ground spacing; therefore, it can easily be collected rapidly. Because of the different adjoining features, reflectance, elevations, etc., the correlation may not find the location precisely, but this uncertainty can be

predicted. In practice the DEM are edited manually. Most soft photogrammetric software have the capability to do so. Only soft photogrammetry can automatically extract DEM, neither analytical nor analogue photogrammetry can do so. Extraction of DEM in terrestrial photogrammetry is difficult as

$$\frac{dh}{H} \gg 0.1 \text{ and the range is difficult to define.}$$

2.1. Soft Photogrammetry and GIS

Geographic Information System (GIS) is a layer of computer maps with attribute data for all points, lines, and polygons in the map of a given geographic area. GIS software enables one to display, query, and analyze the data using the computer maps and attribute data stored in the database.

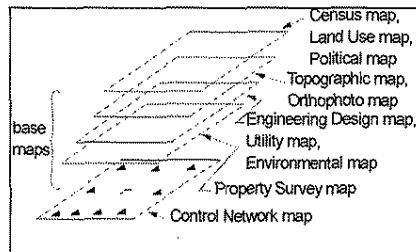


Figure (2.13)

The GIS Concept

Figure 2.13. shows the different layers of maps used in GIS. The control network map shows the ground control points that are used to link layers of maps for a given area and maps of different areas.

The accuracy of the ground control point locations may vary from ± 1 cm to ± 100 m. The ground control points could be displayed in different coordinate systems such as spherical coordinates (ϕ , λ , h),

state plane coordinates (N, E, elevation), and Universal Transverse Mercator (UTM) coordinates. The layers of maps of different scale and accuracy are produced using some or all of the same control points, and these maps can therefore be linked together. At present, the most accurate ground control points are determined by GPS. As seen in Figure 2.13., the base maps that control GIS are the control network, topographic, orthophoto, and cadastral survey maps. Aerial triangulation in soft photogrammetry can be used to determine the spatial coordinates of a number of control points. Soft photogrammetry can also be used to produce the topographic and orthophoto map. "As-built" and cadastral survey can be produced by soft photogrammetry. Soft photogrammetry is therefore invaluable for producing and maintaining a GIS.

2.2. SoftPlotter

“SoftPlotter” is a soft photogrammetric software developed by Autometric and currently marketed by Vision International. The SoftPlotter is designed to run on a high -performance Silicon Graphics hardware workstation. A specially developed three-dimensional (3-D) input device (3-D Softmouse with foot pedal) suitable for intensive operator interaction, a dual-headed hardware configuration, crystal eye stereo emitter for displaying the stereo image, and crystal glass eyewear for viewing the stereo image are part of the system. The system needs about 64 MB memory for processing the data and about 2 to 6 GB of internal and external disk space for data storage. The software generally comes in CD and tape. In this setup, the CD is used as an input device and the tape for both input/output. The system can also be connected as a network that can be used to transmit data and for operating from a remote workstation. The software and data are usually backed up on the tape every week. Appendix A illustrates the hardware setup.

The SoftPlotter is organized into tools. The tools communicate via data files and are individual executables with subordinate executables. Figure 2.14 shows the different executable tools.

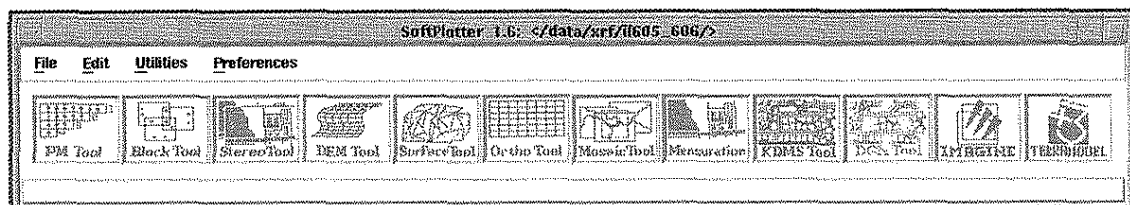


Figure 2.14. SoftPlotter Primary Menu

The concept of a “project” is used by the product to force a *de facto* organization on the user. The Production Manager (PM) tool provides for project visualization and data management. Block tools enable the user to measure photo coordinates, input ground coordinates and camera calibration data, and

determine the exterior orientation parameters. Stereo tool enables the user to view stereo; DEM tool enables the user to create automatic DEM, Surface tool enables the user to edit DEM, Ortho tool to create orthophoto, KDMS tool plots planimetry, and Imagine facilitates image classification. Appendix B describes the software setup.

A number of soft photogrammetry software are available. A comparison of the different software was done. However, a comprehensive study of the software is not possible because access to the software and special hardware was not available. Appendix C gives a brief comparison of SoftPlotter with "Socket," a software developed by Leica, that can run on SGI. It also compares SoftPlotter with Intergraph, which runs on Intergraph workstations, and SoftPlotter with TNTMips, which runs on PCs. SoftPlotter is comparable or better than the other soft photogrammetric software available.

CHAPTER 3. CAMPUS PROJECT

In 1994 aerial photographs were taken of the Iowa State University (ISU) main campus. The control and check points for these photographs were established with Global Positioning System (GPS). The photographs were scanned using a HP ScanJet 3C with a resolution of 300 dots per inch (dpi) ($\approx 80 \mu\text{m}$), available at no cost for this research. These digital images were used to familiarize the researchers with the soft photogrammetric technology. Using the ISU equipment, the researchers evaluated the accuracy of the soft photogrammetry in this research.

3.1. Accuracy of Photo Coordinates

The accuracy of photo coordinates depends on scanner resolution and the pixel size of the scan. The scanners used in soft photogrammetry are Vexcel and Wehrli, which are very expensive.

A test was conducted to evaluate the accuracy of the scanners, HPScanJet 3C and 4C. The 4C has a resolution of 40μ or 600 dpi. These scanners have a size limitation of only about 90% of the standard 23 cm x 23 cm aerial photograph and can be scanned in the x direction, while its full length can be scanned in the y direction, giving about a 10% overlap between adjacent models in a strip, which is acceptable for this research. Because of the size limitation, only five of the eight fiducials can be used for interior orientation, which is sufficient.

The root mean square (RMS) errors after interior orientation using ScanJet 3C and 4C with different pixel sizes are shown in Figure 3.1. and 3.2. For a 25- μm pixel size, the optimum RMS for 3C is about 30 μm and for 4C is about 10 μm . Thus the accuracy depends on the scanner resolution and not on the pixel size.

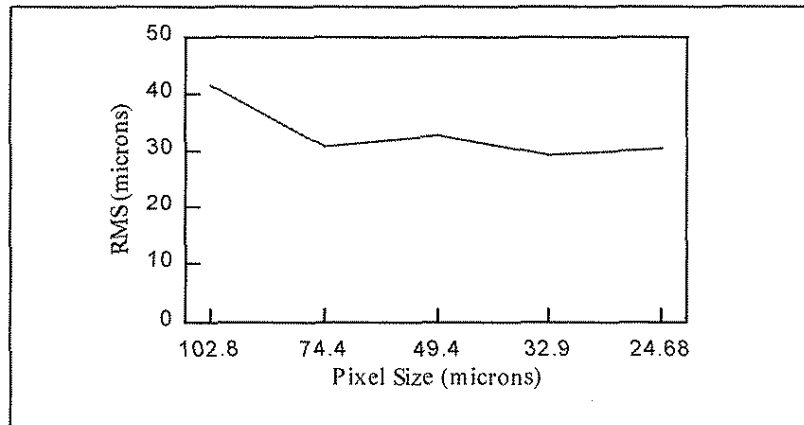


Figure 3.1. RMS vs. Pixel Size for HP ScanJet 3C

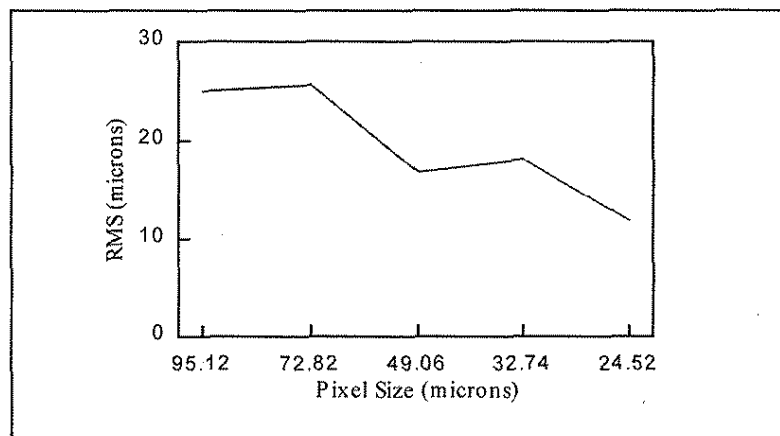


Figure 3.2. RMS vs. Pixel Size for HP ScanJet 4C

The resolution of an aerial camera is about 20 μm . From the above figures, the maximum expected accuracy of measurement from this imagery is about 8 μm . Thus if using the 3C scanner produces an accuracy of 30 μm , then using the 20- μm resolution scanner should provide an accuracy of 10 μm or better.

Since a 25 μm x 25 μm pixel size gives about 84 Mb of pixels for a standard 23 cm x 23 cm aerial photo, the HPScanJet 3C with 25 μm pixel was used in this project.

To test the accuracy of soft photogrammetry in determining the photo coordinates, the measurements of points obtained in 1993 using a Wild stereo comparator were used for comparison. Table 3.1 shows the difference in the coordinates obtained by soft photogrammetry and by the stereo comparator. Points with difference $> 100 \mu\text{m}$ are due to the fact that the points measured are not the same. Differences of about $40 \mu\text{m}$ to $50 \mu\text{m}$ in pass point coordinates are attributable to the inability of the Wild comparator, unlike SoftPlotter, to identify and measure the coordinates on adjacent photos simultaneously. Table 3.1. shows that the standard error of difference in the photo coordinates is about $40 \mu\text{m}$, which agrees with the expected accuracy in the difference of the coordinate because the scanner accuracy is $30 \mu\text{m}$ and the accuracy of the pass point coordinates of the Wild comparator is about $20 \mu\text{m}$.

Table 3.1. Comparisons of Photo Coordinates between SoftPlotter and Comparator

“ * ” for difference larger than 100 micrometers. All numbers are in micrometers							
Image Measurements for Photograph No. 9401							
Point ID	From SoftPlotter		From Comparator		Differences		Remarks
	Film X	Film Y	Photo X	Photo Y	ΔX	ΔY	
161	-932.15	79119.03	-905.10	79101.50	-27.05	17.53	
162	-9188.80	16298.20	-9152.80	16310.90	-36.00	-12.70	
163	-13443.38	-43817.30	-13428.00	-48813.45	-15.38	-3.85	
172	34535.24	6967.18	34520.00	6946.80	15.24	20.38	
1710	61363.68	73614.46	61354.60	73613.60	9.08	0.86	
173	69772.81	-60582.64	69751.00	-60571.30	21.81	-11.34	
1720	57897.44	6062.60	57853.70	6050.20	43.74	12.4	
943	20856.81	37374.15	20909.80	37343.50	-52.99	30.65	
941	78680.45	71488.16	74932.10	74400.21	3748.35	-2912.05	**
942	76788.05	12908.68	76087.90	12980.40	700.15	-71.72	*
944	63187.59	-38611.80	63270.20	-38631.61	-82.61	-19.81	
STD of the differences excluding					X	Y	
the ones with “ * ”					40.29	27.65	
Image Measurements for Photograph No. 9402							
Point ID	From SoftPlotter		From Comparator		Differences		Remarks
	Film X	Film Y	Photo X	Photo Y	ΔX	ΔY	
161	-94511.13	81606.84	-94331.40	81612.00	-179.73	-5.16	*

162	-102560.90	16657.24	-102394.51	16675.00	-167.39	-17.76	*
163	-106505.31	-50540.21	-106359.00	-50540.40	146.31	0.19	*
172	-56043.80	8455.56	-55935.00	84672.00	-108.8	-11.64	*
1710	-28013.32	77881.22	-27943.00	77900.50	-70.32	-19.28	
173	-17416.02	-59775.31	-17407.00	-59788.50	-9.02	13.19	
1720	-3 1263.23	8306.74	-31220.00	8310.40	-43.23	-3.66	
181	42941.05	73319.71	42879.40	73289.70	61.65	30.01	
1820	41436.42	10818.99	41358.00	10779.60	78.42	39.39	
943	-71075.64	39292.31	-70909.00	39300.02	-166.64	-7.71	*
941	-9453.54	76237.38	-13484.00	79128.20	4030.36	-2890.82	**
942	-11185.8	15974.92	-11909.00	16048.10	723.20	-73.18	*
944	-24116.63	-37433.31	-23993.10	-37431.10	-123.53	-2.21	*
945	42659.98	-17636.50	41314.50	-14172.50	1345.48	-3464.00	**
946	30141.46	76223.35	33131.60	76182.90	-2990.14	40.45	*
STD of the differences excluding					X	Y	
the ones with “ * “					58.21	28.48	
Image Measurements for Photograph No. 9403							
	From SoftPlotter		From Comparator		Differences		
Point ID	Film X	Film Y	Photo X	Photo Y	ΔX	ΔY	Remarks
173	-109678.47	-54919.60	-109677.00	-54948.93	-1.47	29.33	
181	-44340.89	82497.33	-44350.50	82450.20	8.61	47.13	
1820	-47050.95	17200.77	-47054.10	17163.20	3.15	37.57	
941	-100954.80	85496.31	-105472.11	88472.30	4517.31	-2975.99	**
942	-103389.80	22453.43	-104189.13	22505.80	799.33	-52.37	*
945	-45495.74	-12047.81	-46991.00	-8523.80	1495.26	-3524.01	**
946	-58222.93	85553.60	-54978.00	85450.20	-3244.93	103.40	**
STD of the differences excluding					X	Y	
the ones with “ * “					5.36	42.53	

3.2. Accuracy of Aerial Triangulation by Soft Photogrammetry

The accuracy of triangulation depends on the ground coordinates of control points and the photo coordinates of control and tie points, the resolution of the imagery, the percentage of overlap between photos, the scale of photos, the camera, and the atmospheric conditions. Here, the objective is to study the accuracy of aerial triangulation by soft photogrammetry using the imagery scanned by the ScanJet 3C from a 1993 campus 1:3000 scale photograph and to compare the results by analytical photogrammetry.

The analytical photogrammetric aerial triangulation was done by two software packages: Albany (an industrial software) and Calib (a research software).

In SoftPlotter, the scanned imagery is imported and stored in the job data directory together with the camera data using the “PM” tool. The “Block” tool is then activated and the imagery is calibrated. The pixel coordinates of pass points and control points are measured simultaneously, either automatically or manually, on three adjoining photographs. The coordinates of ground control points and any available values of exterior orientation elements are added. The triangulation software is then executed and the results are viewed.

3.2.1. Results of aerotriangulation

Three different types of aerotriangulation methods are used here. They are Albany from ERIO, Calib from Jeyapalan, and SoftPlotter from Vision International. The results from the three different software are shown in Table 3.2.

Table 3.2. Comparison of Triangulation Results Using Three Different Software Packages

Parameter	Photograph No. 1			Photograph No. 2		
	SoftPlotter	Albany	Calib	SoftPlotter	Albany	Calib
$X_0(\text{meters})$	1487238.563	1487238.563	1487239.2576	1487792.068	1487791.822	1487791.8651
$Y_0(\text{meters})$	1058385.185	1058385.689	1058386.2669	1058411.816	1058411.773	1058412.3437
$Z_0(\text{meters})$	1229.815	1230.691	1203.4923*	1230.331	1230.980	1203.7212*
$\omega(\text{degrees})$	2.4992711	2.7455	2.1695047	2.4138072	2.6714	2.41656409
$\phi(\text{degrees})$	-2.6663514	-2.9648	-2.6786350	-2.7655344	-3.0804	-3.49479308
$\kappa(\text{degrees})$	4.5477386	5.0931	4.2312360	2.7041475	7.1378	2.55292799

The heights with “*” are ellipsoid heights. The geoid undulation in the Ames area is about 29 meters; therefore, the heights above mean sea level for the two exposure stations are close to 1,230

meters. The above table shows that the results are close, especially those from SoftPlotter and Calib.

Note that the exterior orientation elements from Albany are the estimated values prior to the final ground coordinate computation.

3.2.2. The comparison of triangulation between SoftPlotter and Albany

Table 3.2.1 shows the comparison between the triangulation from SoftPlotter and Albany. In the determination of the exterior orientation parameters, the differences in x, y and z of the camera locations are about half a meter, and the differences of angle ω and ϕ are about 0.05 degrees. However, the difference of κ is about 2 degrees. The differences of the ground point locations are about 0.25 meters in the x and y directions and 0.46 meters in the z direction.

Table 3.2.1

Table 2. Comparison of Triangulations between Softplotter and Albany								
Frame Parameters From Softplotter (Unit is Meter)								
Frame	Desc/Cam		X	Y	Z	Omega	Phi	Kappa
19401		1	1487238.563	1058385.185	1229.815	2.499271	-2.666351	4.547739
29402		1	1487792.068	1058411.816	1230.331	2.413807	-2.765535	2.704148
39403		1	1488345.696	1058425.273	1230.067	0.878105	-2.686623	2.523878
Frame Parameters From Albany (Unit is Meter)								
Frame	Desc/Cam		X	Y	Z	Omega	Phi	Kappa
19401		1	1487238.563	1058385.689	1230.691	2.7455	-2.9648	5.0931
29402		1	1487791.822	1058411.773	1230.98	2.6714	-3.0804	7.1378
39403		1	1488346.495	1058424.595	1230.283	0.9978	-2.9238	7.2753
STD in Meters:			0.446087	0.482995	0.273784	0.0625	0.033432	1.912263
			Current Position From Albany			Current Position from Softplotter		
Point ID	Type	Description	X	Y	Z	X	Y	Z
161	I	X	1487238.218	1058922.793	292.176	1487237.92	1058922.102	292.434
162	C	Tennis Court	1487217.821	1058522.447	291.047	1487217.88	1058522.182	291.021
163	H	Lnc. W	1487223.801	1058124.074	291.242	1487223.84	1058124.315	291.277
172	C	Black Eng.	1487494.664	1058486.702	290.61	1487494.56	1058486.756	290.659
1710	I	Metal	1487640.461	1058930.904	288.921	1487640.19	1058930.648	288.443
173	C	Lnc. M	1487748.207	1058082.75	284.719	1487748.16	1058082.621	283.528
1720	I	B.H.	1487643.634	1058493.224	290.899	1487643.62	1058493.276	290.455
181	C	Horse	1488093.578	1058937.705	281.399	1488093.64	1058937.805	281.389
1820	I	Ross	1488096.568	1058532.161	283.606	1488096.9	1058532.499	283.771
943	I		1487394.974	1058669.981	293.346	1487394.44	1058669.792	293.167
941	I		1487730.061	1058945.934	287.937	1487756.34	1058929.896	286.066
942	I		1487759.159	1058547.007	290.288	1487763.84	1058547.008	289.017
944	I		1487700.773	1058214.828	279.697	1487700.24	1058214.947	278.605
945	I		1488103.168	1058374.505	278.967	1488113.11	1058353.262	276.891
946	I		1488028.617	1058951.089	283.598	1488009.14	1058949.756	283.344
STD in Meters, excluding Pt # 941, 942 :						0.253074	0.275035	0.461847

In summary, the differences in resection (position and attitude of camera) by soft photogrammetry and those determined by the Albany and Calib software are less than 1 m in the x, y, and z positions and

less than 0.1 degrees in attitude angles. The differences in intersection coordinates of tie points (T) and control points (C) on ground by soft photogrammetry and by Albany are less than 0.3 m in x and y and 0.5 m in z. The observed differences are due to the use of comparator coordinates in Calib and Albany and to the use of pixel coordinates in SoftPlotter. The differences may also be due to identifying the same "tie" points, which are not targeted.

3.3. Accuracy of Auto Correlation by Soft Photogrammetry

Auto correlation is the technique that automatically matches points in a stereo pair. To test the accuracy of SoftPlotter in performing the auto correlation, the "stereo" tool is activated. After triangulation, it uses the exterior orientation elements to rectify the photos and create the stereomodel in the epipolar coordinates. This is followed by activating the "DEM" tool, which automatically determines elevations at specified grid intervals. Points with bad, poor, and good auto correlation are color coded by red, yellow, and green, respectively. A grid interval of 10 m was selected for this test.

The same stereo model is then set up on the analogue stereoplotter, Kelsh. Kelsh is a third-order stereoplotter with a C-factor of 750, meaning that the accuracy of Kelsh elevations for a 1,200 m flying height is about 2 m. Elevations at grid intervals of 10 m are mechanically determined. This is a tedious, time-consuming procedure unlike the automatic DEM in SoftPlotter.

The DEM from Kelsh and SoftPlotter are imported to the "Surfer." Surfer is software that uses the (x, y, z) coordinates of an area or the DEM to create and display contours and surfaces. The Surfer used in this research runs on a personal computer. Figures 3.3. and 3.4. show the contours from Kelsh and Softplotter. And Figure 3.5. shows the difference in the contours. Figures 3.6. and 3.7. show the surface from Kelsh and SoftPlotter. Figure 3.8. shows the differences in the surfaces. When compared with that of the manual model using the Kelsh, the standard error of auto correlation of the DEM by soft photogrammetry is about 5 m. Spot elevations of points with large differences were investigated; they

were attributable to the third-order Kelsh. (see Table 3.3.) Table 3.4. shows (x, y, z) and Z difference for some of the 1,630 points used in this study.

Overall, the SoftPlotter auto correlator appears to be much more accurate than the Kelsh system. However, there appears to be some difficulty with SoftPlotter auto correlation in the "Power Plant area," perhaps resulting from the overlap of photographs, which tends to "cluster" data points near that area. However, in other areas, the auto correlated data (refer to data outside three standard deviations) was very similar to the manually correlated Z-coordinate data.

The time difference regarding the collection and display of data for Kelsh and SoftPlotter data appears to be quite large. First, Kelsh data must be read, point by point, from the aerial photographs, which can take many hours. Then these points need to be read into a database. This procedure took approximately 12 hours. The SoftPlotter data, however, is scanned into the computer and the analysis is performed in seconds. The results can then be directly entered into a database.

Results

The mean of the difference in Kelsh and SoftPlotter data is 1.556833. The standard deviation is 5.1888958

Table 3.3. Comparison of Data Points Outside Three Standard Deviations

Pt. #	Z-coordinate	Z-coordinate	Z-coordinate	Color of	Ground
	sp-manual	sp-autocorr.	Kelsh	Point	Features
1	276.412	276.604	293.628	red	trees and grass
2	278.869	278.207	293.214	red	trees
3	276.518	275.945	291.731	red	grass and a tree
4	301.408	302.236	286.180	red	Bessey Hall, S edge
5	276.159	266.504	298.461	red, yellow	Power Plant Bld.
6	276.731	271.542	294.775	red	Power Plant Bld.
7	305.364	303.409	286.783	green	top of Bessey Hall
8	306.354	302.513	286.907	yellow,	Bessey Hall

9	281.313	272.238	293.978	green red	Power Plant Bld.
10	283.551	260.675	296.062	red and yellow	Power Plant Bld.
11	284.176	264.545	289.779	yellow	Power Plant Bld.
12	307.186	306.092	288.736	green, yellow	top of Bessey Hall
13	265.948	269.796	287.831	yellow	Power Plant Bld.
14	270.953	274.540	296.056	yellow, red	Power Plant Bld.
15	273.608	267.796	285.003	red	Power Plant Bld.
16	280.948	265.259	281.776	yellow	Power Plant Bld.
17	299.534	300.992	284.151	yellow, red	Bessey Hall
18	274.337	274.803	293.129	yellow	Power Plant Bld.
19	278.293	270.424	312.022	yellow	tree near P.P.P
20	277.000	267.129	284.860	yellow	road by P.P.B

Table 3.4. Difference Between Kelsh and SoftPlotter Z-Coordinate Values

kelshz-Kelsh			SoftPlotter		z-soft		difference	
							zk-zs	
1487900	1058200	280.901	1487900	1058200	286.921	-6.02		
1487920	1058200	281.394	1487920	1058200	287.016	-5.622	Diff-mean	
1487930	1058200	281.226	1487930	1058200	283.594	-2.368	1.556833	
1487950	1058200	280.546	1487950	1058200	281.81	-1.264		
1487960	1058200	280.609	1487960	1058200	284.372	-3.763	Kel-Soft	
1487980	1058200	279.876	1487980	1058200	289.372	-9.496	STD	
1487990	1058200	279.287	1487990	1058200	289.789	-10.502	5.188958	
1488010	1058200	280.935	1488010	1058200	289.017	-8.082		
1488020	1058200	285.09	1488020	1058200	287.932	-2.842		
1488040	1058200	284.59	1488040	1058200	286.317	-1.727		
1488050	1058200	283.293	1488050	1058200	286.651	-3.358		

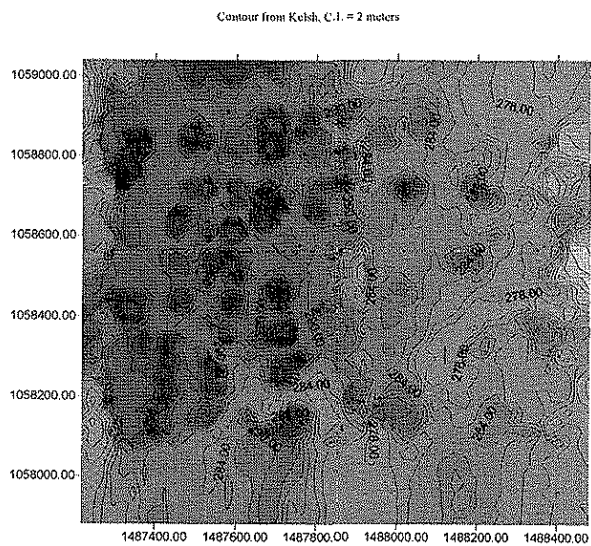


Figure 3.3.

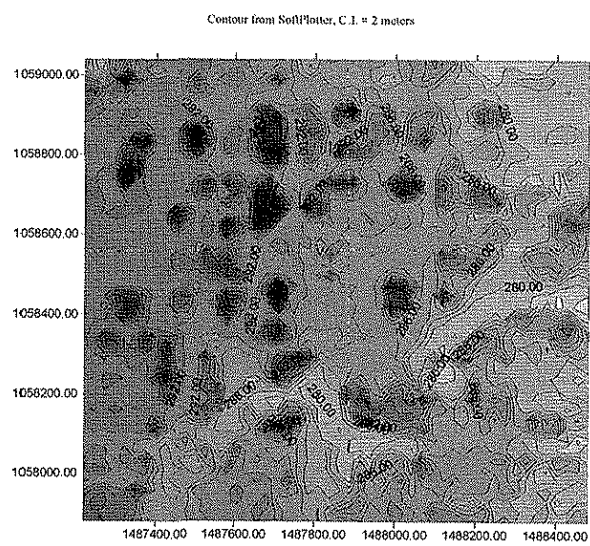


Figure 3.4.

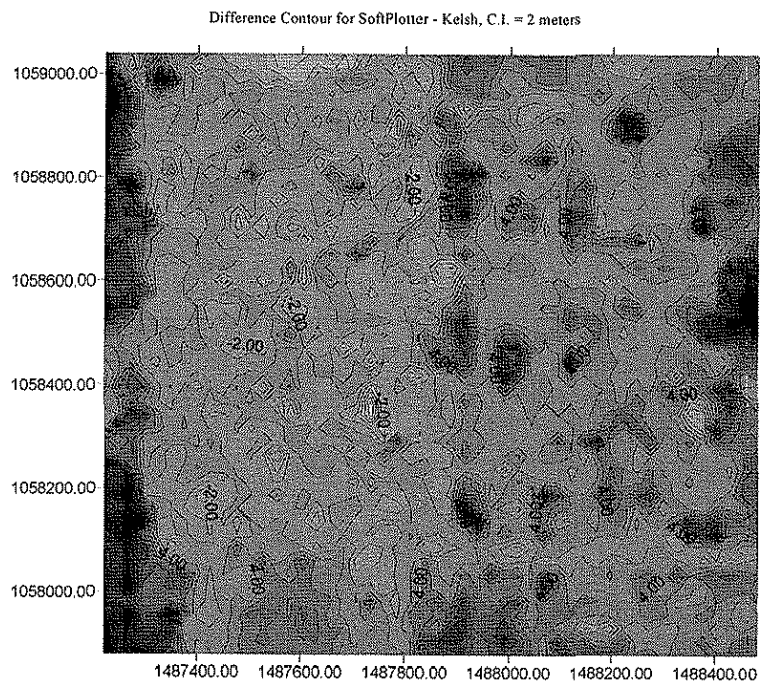


Figure 3.5.

Surface from Kelsh

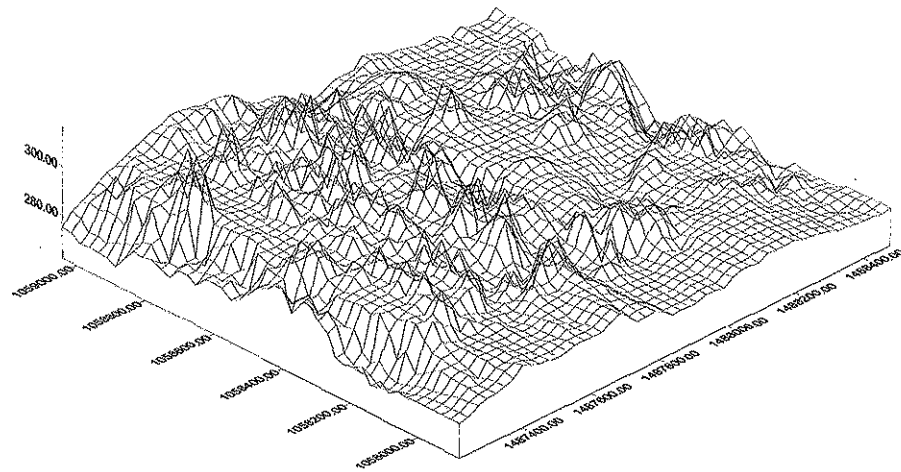


Figure 3.6.

Surface from SoftPlotter

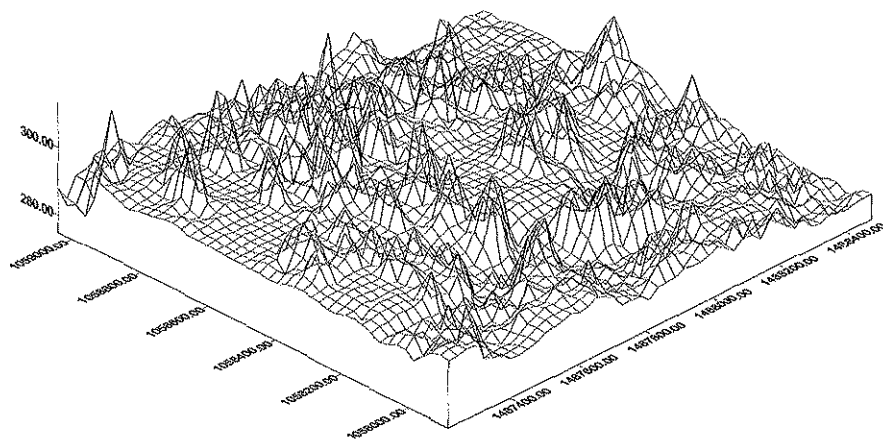


Figure 3.7.

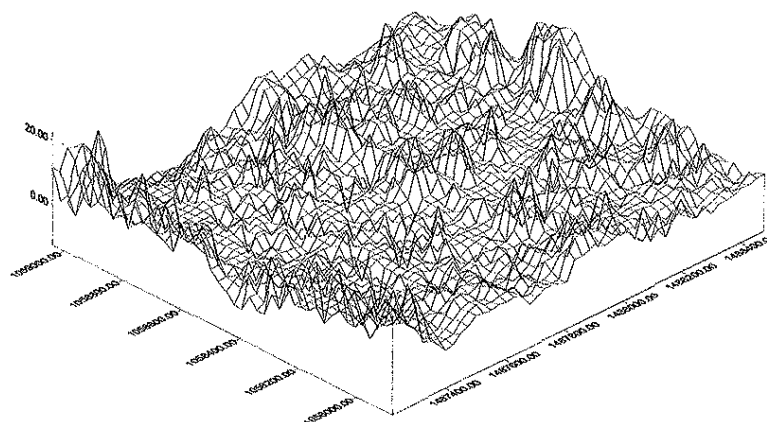


Figure 3.8.

3.4. Accuracy of SoftPlotter Compared to a First-order Stereoplotter Zeiss C8

The Zeiss C8 Stereoplotter is a first-order stereoplotting instrument. It has the capability to read model coordinates to an accuracy of ± 0.01 mm, and it has the facility and the Zeiss parallelogram to perform strip triangulation. The objective in this study is to set up the same stereo pair used in SoftPlotter in the Zeiss C8 and determine the accuracy of SoftPlotter by comparing the ground coordinates obtained by the two systems. Also, a study comparing SoftPlotter to Zeiss C8 was done.

3.4.1. Zeiss vs. SoftPlotter

For this project, the Zeiss stereoplotter took approximately three times longer than the Softplotter to set up a stereo model and perform triangulation. Using the Zeiss requires knowledge of photogrammetric principles, familiarity with the instrument and its components, the time necessary to orient the photos for stereo viewing, and the time required to read the points. Additional time is required for postprocessing because the user must convert the machine coordinates from the Zeiss readings to ground coordinates using external processing programs. The instrument may not be used for other

puposes until the process of triangulation is completed because the stereo model and its orientation cannot be disturbed.

<u>Procedure</u>	<u>Time (approximation)</u>
Setting up the stereo model	8 hours
Scaling	2 hours
Leveling	2 hours
Reading points	8 hours
<u>Transformation to ground</u>	<u>8 hours</u>
Total	28 hours

3.4.1.1. SoftPlotter.

The SoftPlotter requires data in digital format. To acquire digital data in this project., the hardcopy was converted to digital format using a scanner. If more photos are used, the time factor would increase for this step. However, using existing digital data would eliminate the need for this process. Using the stereoplotter for triangulation requires a familiarity with the software's organization. Users who are familiar with windows-type applications should be able to learn the process. The process of reading points is much faster and easier on SoftPlotter than on the Zeiss, because the user can quickly move to the general location of the points. On the Zeiss, the process is done by manual hand-wheeling. Point reading is also easier and faster on the SoftPlotter because the optics are much clearer. The special glasses required for stereo viewing are fairly lightweight and not too uncomfortable. Due to its age, the viewing system on the Zeiss used in this project suffers from loss of clarity. The instrument has also been moved several times. The stereo model setup is saved in a file for future use, which allows the SoftPlotter to be used for other projects without loss of the user's work.

<u>Procedure</u>	<u>Time (approximation)</u>
Digitizing data	1 hour
Setting up stereo model	4 hours
<u>Reading points</u>	<u>5 hours</u>
Total	10 hours

3.4.2. Comparison of Zeiss coordinates to SoftPlotter coordinates

In the Zeiss C8, after relative and absolute orientation, the model coordinates are read in mm. These model coordinates (x_m , y_m , z_m) are then transformed to ground coordinates using the control points and the transformation equation:

$$\begin{pmatrix} x_g \\ y_g \end{pmatrix} = \begin{pmatrix} A & B \\ -B & A \end{pmatrix} \begin{pmatrix} x_m \\ y_m \end{pmatrix} + \begin{pmatrix} x_0 \\ y_0 \end{pmatrix}$$

$$S = \sqrt{A^2 + B^2}$$

$$Z_G = SZ_m + CX_m + DY_m + Z_0$$

The transformation parameters are A, B, C, and D. Table 3.5. shows the results where

Note: $z_g = c*y_m - d*x_m + s*z_m + z_0$

Standard deviation or s:

X_g, Y_g, Z_g = Zeiss ground coordinates

X_s, Y_s, Z_s = SoftPlotter ground coordinates

$s X = 0.779$

$s Y = 0.251$

$s Z = 4.472$

The spreadsheet contains machine and ground coordinates of the points read on Zeiss; ground coordinates of the points read on SoftPlotter; results for differences in x, y and z; and the standard deviation of x, y, and z. A comparison between SoftPlotter and Zeiss values for the x, y, and z ground coordinates shows them to be fairly close. The difference is less than 1 m for most points, except for the z ground coordinates obtained from the Zeiss for any buildings. The z ground coordinate value for points read on top of buildings on the Zeiss is within 1 meter or less of the values for ground coordinates of points read on the ground on Zeiss but should be around +20 meters difference, depending on the height of the building. The Zg-Zs for the buildings range from about -9.711 to -33.703; the standard deviation for z is 4.47. Point numbers beginning with 5 are points on the ground. Points numbers beginning with 7 are points on the top of buildings. The model on Zeiss may have some distortion at the edges.

Table 3.5. Ground Coordinates from Ziess C8 Model Coordinates

Point #	Y Value	X Value	Z Value	Xg	Yg	Zg	Xs	Ys	Zs	Xg-Xs	Yg-Ys	Zg-Zs	
172AN	806.5	-363.4	535.97	1487643.63	1058493.22	290.88	1487644.19	1058493.11	289.3	-0.56	0.11	1.6	
942	859.81	-464	535.97	1487758.68	1058547.22	290.28	1487759.44	1058546.96	289.2	-0.76	0.26	1.13	
9411	1034.8	-448.7	535.95	1487751.14	1058743.23	287.33	1487751.59	1058743.16	289.4	-0.45	0.07	-2.03	
943	953.89	-132.8	539.42	1487394.36	1058670.16	293.36	1487393.90	1058670.63	292.7	0.46	-0.47	0.649	
9410	960.07	41.15	537.86	1487200.72	1058686.50	290.26	1487201.81	1058686.19	290.9	-1.09	0.31	-0.68	
162	813.75	19.48	536.62	1487216.94	1058522.12	290.73	1487217.20	1058522.72	289.9	-0.26	-0.61	0.812	
947	733.7	21.26	537.72	1487210.60	1058432.92	293.82	1487211.56	1058433.44	292.7	-0.96	-0.52	1.099	
949	747.37	-176.4	535.88	1487431.83	1058437.43	291.18	1487432.07	1058437.55	290.9	-0.24	-0.12	0.238	
172	794.18	-230.5	535.9	1487494.66	1058486.70	290.6	1487494.63	1058486.77	290.6	0.04	-0.07	0.024	
551	685.05	5.77	542.88	1487225.23	1058377.81	302.97	1487222.29	1058378.30	292.8	2.94	-0.49	10.12	
751	740.18	-73	548.03	1487316.09	1058435.03	310.57	1487316.21	1058435.51	303.6	-0.11	-0.49	6.934	
752	761.63	-55.03	548.42	1487297.22	1058459.93	310.79	1487297.41	1058460.43	304.4	-0.19	-0.50	6.441	
552	874.08	30.57	534.9	1487207.85	1058590.01	286.94	1487208.61	1058590.11	288.3	-0.76	-0.10	-1.32	
553	961.35	-12.9	539.18	1487261.08	1058684.99	292.52	1487260.78	1058685.15	292.3	0.30	-0.16	0.185	
753	989.2	-59.3	559.95	1487314.35	1058713.54	325.62	1487315.48	1058713.39	317.5	-1.14	0.14	8.159	
754	979.29	-33.89	560.96	1487285.47	1058703.86	327.34	1487285.96	1058704.00	315.4	-0.50	-0.14	11.91	
554	966.24	-81.51	540	1487337.87	1058686.72	293.95	1487338.32	1058686.62	293.3	-0.44	0.09	0.611	
555	870.16	-153.1	537.02	1487412.54	1058575.66	290.93	1487412.81	1058575.71	291.3	-0.27	-0.05	-0.4	
755	1019.2	-258.8	548.54	1487538.54	1058736.19	307.32	1487538.42	1058736.52	302.8	0.12	-0.33	4.524	
556	874.45	-296	537.1	1487572.09	1058572.68	291.39	1487571.93	1058572.53	291.7	0.16	0.15	-0.32	
557	756.98	-276.1	535.55	1487543.59	1058442.73	290.77	1487543.68	1058442.92	290.6	-0.09	-0.19	0.209	
558	777.71	-384.5	535.75	1487665.53	1058459.96	291.06	1487665.52	1058460.18	290.3	0.01	-0.21	0.751	
559	839.78	-395.1	536.36	1487680.79	1058528.62	291.05	1487680.72	1058528.90	291.3	0.06	-0.28	-0.27	
756	820.64	-314.9	554.25	1487590.32	1058511.63	319.94	1487588.96	1058511.91	310.6	1.36	-0.28	9.334	
757	953.39	-365.4	556.03	1487653.79	1058656.96	320.76	1487653.63	1058657.11	312.5	0.16	-0.16	8.306	
560	978.28	-439.4	536.54	1487737.69	1058680.70	289.18	1487738.08	1058680.80	289.9	-0.38	-0.10	-0.75	
561	936.35	-443.6	536.31	1487740.13	1058633.70	289.52	1487740.81	1058633.95	290.1	-0.68	-0.25	-0.54	
562	780.08	-455.3	535.95	1487744.65	1058458.76	291.54	1487744.41	1058458.59	291.1	0.23	0.16	0.47	
758	776.71	-421.4	564.79	1487706.64	1058456.84	337.92	1487705.95	1058457.28	323.3	0.68	-0.44	14.59	
563	777.03	-157.6	536.07	1487412.47	1058471.53	290.95	1487412.71	1058471.83	290.6	-0.23	-0.30	0.378	
A	B	X0	Y0							std dev	0.779	0.251	4.472
1.1154	-0.054	-1E+06	1E+06										
C	D	S	Z0										
-0.016	0.0028	1.6097	-559.6										

The standard error of the differences in position determination by soft photogrammetry and the Zeiss C8 was found to be less than 0.5 m in x and y but about 4 m in z. An examination of the points with large differences was performed. They are mainly on building tops and attributable to the Zeiss C8. It has not been calibrated for the last ten years and the optics need cleaning, which was not done due to lack of funds.

3.5 Accuracy of Planimetry and Orthophoto by SoftPlotter

3.5.1. Planimetry

The “KDMS” tool in SoftPlotter enables the user to collect planimetric data that can be saved as a plot file and plotted according to a specified scale. One objective of this research was to compare the planimetric maps by SoftPlotter and by Kelsh plotter.

After the “Stereo” and DEM, the information is passed on to KDMS. Here one can view the model in stereo and collect the data as in an analogue stereoplotter. Unlike in analogue stereoplotter, the KDMS uses computer-aided drawing (CAD) software to draw selected features. The planimetry in the two stereo models are plotted and exported to AutoCAD as a DXF file. The same stereo pairs are set up on the Kelsh stereoplotter, and the planimetry is manually plotted for each model separately. The plotted map is then digitized using AutoCAD. (AutoCAD is a CAD software that enables different maps to be merged together on the same scale, using a calibration routine.) Using the ground control points as common points, the planimetric maps from the two stereo models are merged.

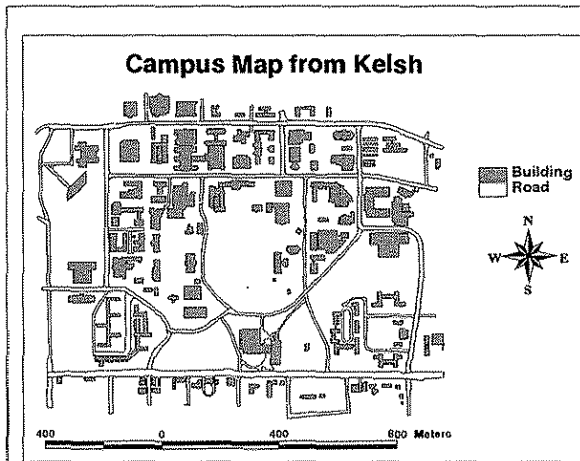


Figure 3.10.

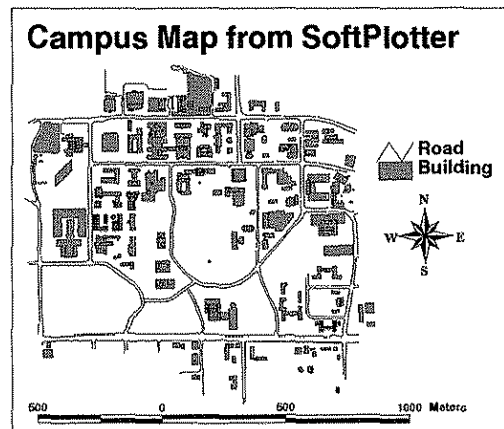


Figure 3.9.

The planimetric maps from SoftPlotter (see Figure 3.9.) and from Kelsh (see Figure 3.10.) are brought to the same scale in AutoCAD and overlaid (see Figure 3.11). The two compare well except in some areas. To get the magnitude of disagreement, the overlays are enlarged and the separation is measured at buildings and road corners.

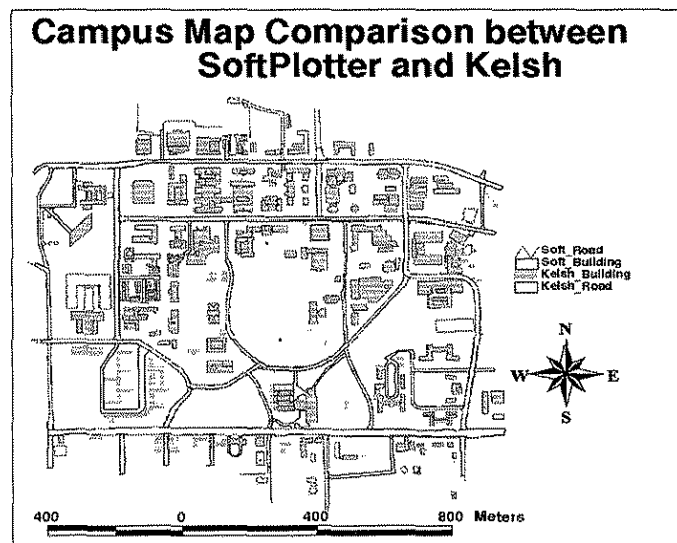


Figure 3.11.

Table 3.6. shows the results of the statistical analysis of the difference between these two planimetric maps. In Table 3 there are eight columns; four of the columns are the differences for roads and the other four columns are for the buildings. NW, NE, SW, and SE describe the regions of the planimetric map. The standard deviations for the whole area are 0.577966 and 0.589102 for roads and buildings, respectively.

Table 3.6

Table 3. Statistical Analysis of the Comparison
Unit: Meters

Roads	Roads	Roads	Roads	Buildings	Buildings	Buildings	Buildings
NW	NE	SW	SE	NW	NE	SW	SE
0.748	0.8118	2.3335	2.7112	1.5199	3.6305	0.2713	1.7711
1.4532	2.07	0.9781	2.4452	0.57	1.0268	0.5427	1.4747
0.3024	0.7967	0.814	2.4444	0.3797	1.2845	0.3836	0.8855
0.6936	0.796	1.8978	2.4444	1.0011	1.0584	1.1171	0.2952
0.3653	0.3984	1.0845	1.0637	1.0002	1.2845	0.7441	1.7955
0.3955	0.796	0.6063	0.5904	1.1864	1.0268	0.7448	0.5904
0.7909	0.398	0.6063	0.5899	0.7909	0.7967	0.7441	0.5899
0.7141	0.796	0.9778	0.4173	0.787	0.7967	0.7447	1.185
0.5476	0.796	0.3724	0.8848	0.8804	0.398	0.5808	1.1854
1.0392	0.4503	1.1171	1.1807	0.8118	1.6412	2.0062	0.3951
0.9326	1.0068	0.7441	0.8855	0.44	0.398	0.2636	0.8841
0.8775	0.4499	0.9477	1.18	1.004	1.1941	0.5267	1.7674
0.4905	1.3509	0.6232	1.1864	1.0392	0.3984	0.4164	0.559
	0.9006	1.1008	0.7909	1.3152	2.3881	0.3954	
		0.7938			1.3498	0.3717	
					0.4503		
					1.3509		
Standard Deviation for Each Column							
0.304316	0.423422	0.490404	0.773811	0.306135	0.78475	0.423041	0.520272
Standard Deviation for Roads and Buildings							
	0.577966					0.589102	

3.5.2. Orthophotos

In SoftPlotter, the "Ortho" tool is used to create the orthophoto of a stereo model. The epipolar coordinates after Stereo and the elevations after DEM are used to create the orthophoto. The orthophoto for the two models is created and then the "Mosaic" tool in SoftPlotter is used to join it, forming the orthophoto. (see Figure 3.12.) The scale of the orthophoto can be selected to cover the map sheet.

The planimetric map by Kelsh is then overlaid on the orthophoto for comparison. (see Figure 3.13.) The edges do not match well mainly because the printer is not a SoftPlotter component. The DEM in the overlapping area may be slightly different for the two models. The matching at the edges between

the two models needs to be improved by using the average DEM for the overlapping area and manually editing some bad points using the “Surface” tool in SoftPlotter.

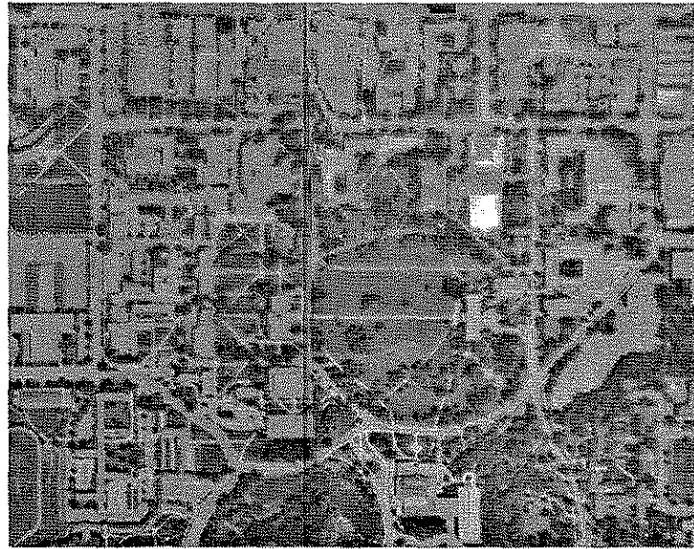


Figure 3.12. Campus Orthophoto

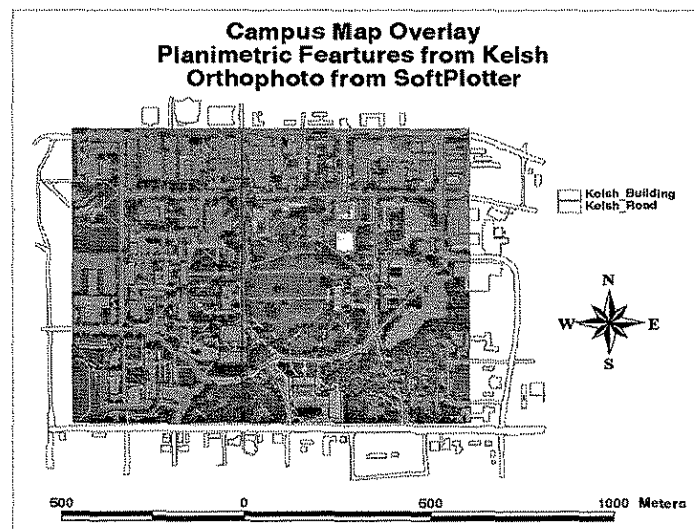


Figure 3.13.

Table 3.7. shows the approximate times taken by the Kelsh and SoftPlotter to create the planimetric map and the orthophoto.

Table 3.7. Comparison of SoftPlotter and Kelsh

Operation	SoftPlotter	Kelsh
Setting up	2 hours	8 hours
Stereo plotting	20 hours	90 hours
Digitizing	-	-
Editing	-	20 hours
DEM	2 hours (depends on spacing)	N/A
Orthophoto	0.5 hours	N/A

3.5.3. Conclusion

From the above results, it is clear that SoftPlotter has the following advantages over the Kelsh stereoplotter:

- The stereo model can be set up easily and quickly. Once the models are in place, they can be used at any time without further time consumption for model setup.
- If the existing stereo models are not good enough or if it is necessary to make comparisons between different parameters, it is easy to set up other models and make such comparisons
- it automatically creates DEM and orthophotos
- manual operation can be used to edit the bad points and areas
- 3-D digitizing ability.
- except for a few bad areas like edges, the orthophoto is close to the manually digitized map

- much faster than Kelsh. All of the photos in the same block can be digitized on the same scale at the same time

The disadvantages are

- the system is expensive
- Some operations cannot be performed in stereo mode

3.5.3.1. GIS and SoftPlotter.

GIS uses information on the features in a computer map to perform a spatial analysis. GIS can also be used to identify selected features in a computer map. In the computer map, the features are mapped using lines, points, and polygons. This is called vector processing. In some computer maps the features are mapped using pixels, which is called raster processing. The KDMS tool in SoftPlotter is used to produce the planimetric maps by vector processing. The "Ortho" tool produces the map by raster processing. The Surfer produces the contour map by vector processing.

Arc/Info is a vector-based GIS software. However, it can also process raster maps. The raster and vector maps produced by soft photogrammetry can be imported into Arc/Info. These can be "cleaned" to ensure that all lines end with nodes and that all polygons are closed. The attribute tables for lines, polygons, and points are "Build." These maps and tables are then viewed by "ArcView," a module in Arc/Info. Additional information about features in the map can be added to the table. The maps and tables can then be used to identify and query features in real time.

In this project, the campus planimetric map by KDMS and the contours by Surfer and Mosaic orthophoto are imported to Arc/Info. (see Figures 3.14., 3.15., 3.16.) The table in Arc/Info is edited to give the names of buildings, roads, and values of contours. (see Table 3.8., 3.9., and 3.10.)

Unlike digitizing from existing maps, the map produced by SoftPlotter photogrammetry is current and accurate. Unlike analytical photogrammetry, both raster and vector can be obtained and exported to the GIS environment in real time.

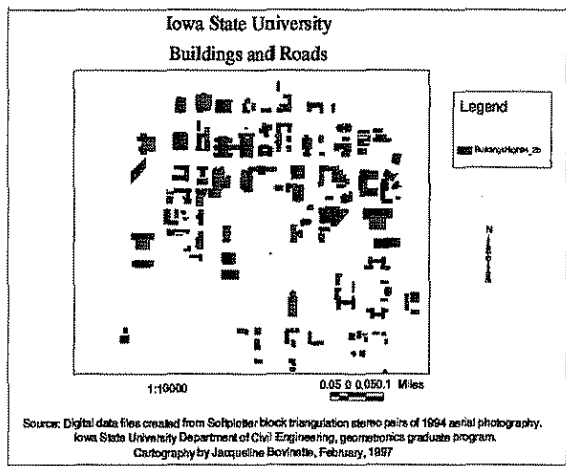


Figure 3.14.

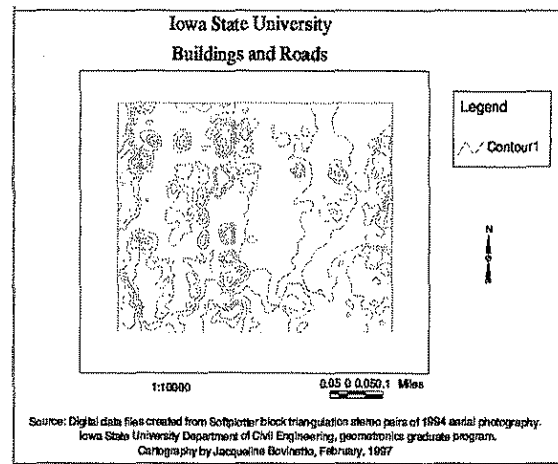


Figure 3.15.

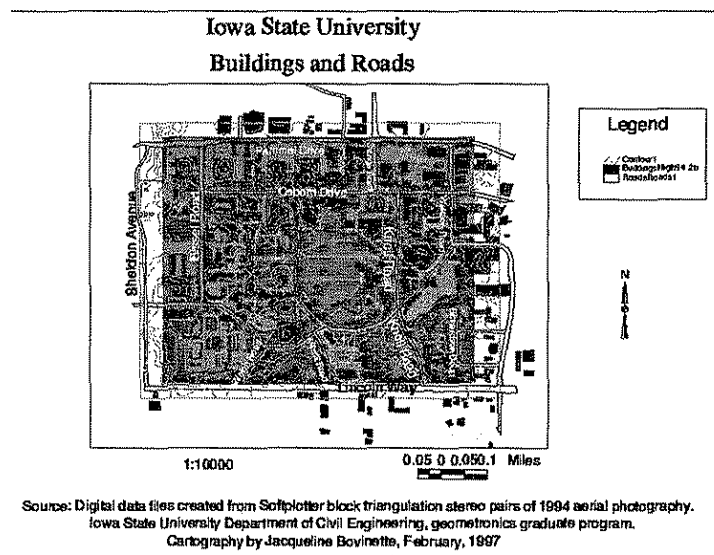


Figure 3.16.

Shape	Area	Perimeter	Campus#	Campus-id	Building_name
Polygon	4547.023	287.163	2	4	Molecular Biology
Polygon	2231.336	382.528	3	5	Industrial Education II
Polygon	514.516	102.260	4	6	Communications Building
Polygon	126.836	48.390	5	7	Genetics Laboratory
Polygon	3510.492	311.128	6	8	Metals Development Build
Polygon	187.109	61.015	7	9	Genetics Laboratory
Polygon	2042.883	189.757	8	10	Communications Building
Polygon	3.516	37.879	9	0	
Polygon	1779.086	247.792	10	12	Horse Barns
Polygon	489.328	92.128	11	13	Genetics Laboratory
Polygon	442.172	96.358	12	14	Ruminant Nutrition Lab
Polygon	50.852	28.897	13	15	Industrial Education II
Polygon	215.312	58.649	14	16	Insectary
Polygon	376.578	85.252	15	17	Insectary
Polygon	543.555	111.390	16	18	Industrial Education I
Polygon	1709.172	217.007	17	19	Science II
Polygon	1718.484	291.383	18	20	National Soil Tilth Lab
Polygon	904.000	163.379	19	21	Lagomarcino Hall
Polygon	3.047	32.883	20	22	
Polygon	407.539	83.895	21	23	Lagomarcino Hall
Polygon	26.688	27.762	22	24	
Polygon	372.516	78.511	23	25	Lagomarcino Hall
Polygon	2775.367	381.757	24	26	Davidson Hall
Polygon	49.000	32.501	25	27	Metallurgy Building (Will
Polygon	657.125	113.547	26	28	Agronomy Greenhouse
Polygon	648.125	123.648	27	29	Greenhouse
Polygon	4420.961	268.639	28	30	Armory
Polygon	1126.812	167.255	29	31	Lagomarcino Hall
Polygon	5458.977	445.887	30	32	Physics Hall
Polygon	4518.117	376.003	31	33	Town Engineering Building
Polygon	458.391	118.674	32	34	Greenhouse
Polygon	615.984	118.254	33	35	Agronomy Greenhouse
Polygon	523.828	88.576	34	36	Judging Pavilion
Polygon	100.852	45.005	35	37	Meats Lab (new)
Polygon	416.883	88.192	36	38	Lagomarcino Hall
Polygon	1.031	4.250	37	39	

Table 3.8. Attribute Data of Campus

Shape	Area	Perimeter	Campus2#	Campus2-Id	Road names
Polygon	2384.289	655.622	2	13	Winlock Road
Polygon	2523.172	402.255	3	18	Stange Road
Polygon	796.750	190.895	4	20	
Polygon	18315.953	2699.778	5	21	Pammel Drive
Polygon	99178.391	1490.263	6	0	
Polygon	40944.555	811.727	7	0	
Polygon	2458.953	438.985	8	32	Wallace Road
Polygon	2371.820	397.923	9	0	Stange Road
Polygon	7757.406	1762.206	10	23	Sheldon Avenue
Polygon	7413.437	1153.647	11	22	Bissel Road
Polygon	95827.492	1865.083	12	0	
Polygon	9673.055	395.072	13	3	
Polygon	40.898	25.242	14	6	
Polygon	1055.062	266.934	15	7	
Polygon	11256.039	2181.250	16	29	Osborn Drive
Polygon	85.867	34.778	17	10	
Polygon	152815.219	1661.856	18	0	
Polygon	149571.306	1494.849	19	0	
Polygon	50627.893	991.068	20	0	
Polygon	15911.070	3020.168	21	24	Merrill Road
Polygon	5414.289	1432.923	22	27	Knoll Road
Polygon	11996.125	1769.894	23	30	Wallace Road
Polygon	79.336	33.775	24	11	
Polygon	79.859	34.080	25	12	
Polygon	2457.914	508.289	26	33	Union Drive
Polygon	121583.242	1868.755	27	0	
Polygon	1884.912	205.533	28	13	
Polygon	380.172	115.020	29	36	Union Drive
Polygon	95868.484	1215.948	30	14	
Polygon	60086.406	1056.147	31	0	
Polygon	4054.367	968.619	32	28	Richardson Court
Polygon	16830.148	513.629	33	0	
Polygon	1581.281	416.070	34	34	Merrill Road
Polygon	34921.281	808.023	35	0	
Polygon	1833.305	342.342	36	26	Welch Road
Polygon	26181.320	2646.720	37	17	Lincoln Way
Polygon	1624.508	333.457	38	35	Beach Avenue

Table 3.9. Attribute Data of Campus2

Shape	Fnode#	Tnode#	Lpoly#	Rpoly#	Length	Contour1#	Contour1-Id	Contour_elevati
PolyLine	56	58	27	29	207.80110	51	134	300
PolyLine	57	36	21	1	102.37500	52	175	0
PolyLine	58	58	44	7	22.76687	53	72	295
PolyLine	59	59	7	42	106.35137	54	107	295
PolyLine	61	41	1	3	58.75000	55	168	0
PolyLine	62	57	47	1	5.37500	56	175	0
PolyLine	64	62	47	1	1.00000	57	175	0
PolyLine	57	64	47	21	16.47725	58	5	0
PolyLine	65	65	46	21	41.38552	59	6	0
PolyLine	66	66	7	27	292.22993	60	105	295
PolyLine	67	67	7	43	90.87452	61	106	295
PolyLine	68	68	48	45	8.30307	62	19	0
PolyLine	69	69	19	37	178.84258	63	144	3.050000e+02
PolyLine	70	11	3	4	244.82949	64	26	290
PolyLine	70	61	1	3	18.12500	65	169	0
PolyLine	71	71	17	19	368.82452	66	133	300
PolyLine	72	72	21	50	89.55616	67	18	0
PolyLine	73	64	21	1	21.50000	68	175	0
PolyLine	74	74	7	17	433.39515	69	104	295
PolyLine	75	70	1	4	10.37500	70	169	0
PolyLine	76	76	52	11	58.74704	71	56	290
PolyLine	77	77	51	53	115.31953	72	150	310
PolyLine	78	78	7	65	3.11406	73	103	295
PolyLine	79	79	48	51	163.16825	74	143	305
PolyLine	80	80	28	48	213.81074	75	132	300
PolyLine	81	81	57	68	20.50047	76	131	300
PolyLine	82	82	7	28	494.93373	77	102	295
PolyLine	83	83	64	4	105.57786	78	36	300
PolyLine	84	84	71	7	18.63334	79	71	300
PolyLine	85	85	61	63	84.29274	80	130	300
PolyLine	86	86	58	70	74.04827	81	101	300
PolyLine	87	87	68	54	51.11428	82	2	2.650000e+02
PolyLine	88	88	54	21	216.61747	83	7	270
PolyLine	89	89	56	61	144.85289	84	100	295
PolyLine	90	75	45	4	264.43663	85	27	290

Table 3.10. Attribute Data of Contours1

CHAPTER 4. HIGHWAY 218 PROJECT

The objective of the Highway 218 Project was to check the accuracy of the soft photogrammetry products for highway engineering, using the photographs taken over Highway 218. Also this project studied the feasibility of transferring the technology to personnel using the Iowa Department of Transportation's (IA DOT's) analogue and analytical photogrammetry tools.

A strip was used of 11 photographs with 9 horizontal and 12 vertical controls. Since these photographs were used in Highway 218 mapping by the IA DOT, they also had 30 pass points, which were pugged. Pass points were pugged on the center photo and not on the adjoining photos. The films were scanned by a drum scanner, which belongs to the IA DOT, with 900 dots per inch (dpi) resolution.

4.1. Aerial Triangulation

The first step that IA DOT takes when producing topographic maps, profiles, and cross sections using an analogue stereo plotter, the Kern PG2, is an aerial triangulation. The aerial triangulation is done on the Zeiss analytical plotter and Albany software. The aerial triangulation provides pass point coordinates and exterior orientation parameters to set the stereo model in the analogue plotter. The control point information is shown in Table 4.1.

Table 4.1. Ground Controls in the Strip

Point #	Point Type	X	Y	Z
2024	H	1577964.936	1148496.920	
2025	H	1578282.547	1148501.881	
2026	H	1578071.647	1148695.909	
2027	H	1578067.270	1149075.685	
2028	H	1578391.399	1149701.023	
2029	H	1578064.722	1150324.648	
2030	H	1578248.529	1151513.268	
2031	H	1578051.693	1151586.845	
2032	H	1578105.699	1151932.802	
1029	V			310.054
1030	V			302.816
1031	V			294.231
1032	V			289.062

1033	V		298.568
1034	V		297.373
1035	V		287.906
1036	V		287.862
1037	V		287.429
1038	V		287.704
1039	V		290.808
1040	V		288.675

H is the horizontal control point; V is the vertical control point. There are also about 30 pugged pass points on the strip. Since the triangulation is done in the Block Tool of SoftPlotter, all of the control points are input to the ground control table in the Block Tool.

4.1.1. Import of the 11 Photographs and the Interior Orientation

The Jena LMK 1015 camera was used in this project, and its calibration data are available. Before importing the 11 photographs, the camera calibration data must be input to the central camera database in SoftPlotter. After a new block is created for this project, all 11 photographs are imported. The size of each digital photograph is about 64 MB, and the pixel size on the photographs is about 28 μ .

Interior orientation is the process that registers the photographs with the camera photo coordinate system. Figure 4.1. shows the root mean square (RMS) of the interior orientation of these 11 photographs numbered from 152 to 162. All of the eight fiducial points are used in the interior orientation process.

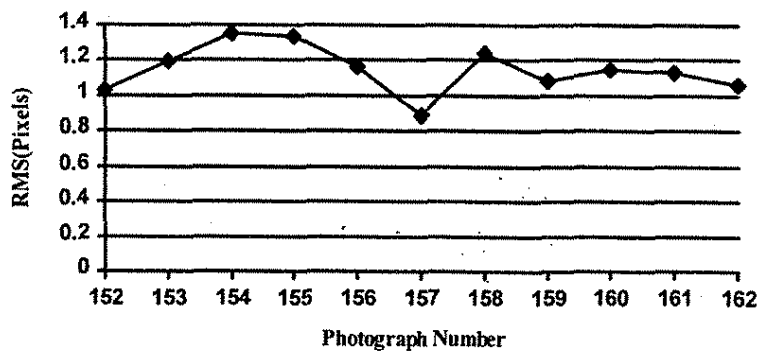


Figure 4.1. RMS vs. Photograph for Interior Orientation

The accuracy of the interior orientation is a little more than one pixel, which is about $30\ \mu$. The scanner used to scan these photographs has a resolution of 800 dpi, which is about $31.5\ \mu$; therefore, the accuracy of the interior orientation may be the best it can achieve.

Also, the residuals in one direction (x in the photo coordinate) are much larger than the residuals in the other direction (y in the photo coordinate). This is related to the way the diapositives were scanned. Although the 800-dpi scanner was used, the geometric distortion in one direction may be larger than the distortion in the other direction. These fiducials might reduce the geometric distortion somewhat.

4.1.2. Measurement of the Ground Controls and the Triangulation

Before completing the triangulation, all of the control points and pass points must be located and measured on the photographs, so that their pixel coordinates are known. Although this process is not under stereo view, each point is separately measured on each photograph. Automatic image matching can be used to locate the identical points on other photographs. Once the point on the reference photograph is located, the approximate locations on the other photographs are determined. This process is very useful when the image quality is not very good, the ground contrast is low, or points are pugged with marks only on one photograph. For these pugged pass points, the photograph with pugged marks is chosen as the reference photograph, the pugged point is precisely located, and the automatic image-matching method is used to locate its identical points on the other photographs. The matching results are very sensitive to the initially estimated locations on the other photographs. For satisfactory results, it is useful to try different locations. Up to six photographs can be displayed at the same time; therefore, more than one model can be measured at a time. After all of the control and past points are measured on the photographs, the triangulation can be performed. Table 4.2. shows the triangulation results.

Table 4.2. Triangulation Results

Photo No.	X(M)	Y(M)	Z(M)	$\omega(^{\circ})$	$\phi(^{\circ})$	$\kappa(^{\circ})$
958152	1578090.024	1148303.807	921.784	0.199622	-1.106869	-91.516184
958153	1578101.079	1148674.483	924.083	0.374820	-0.214692	90.713598
958154	1578092.987	1149035.814	923.711	0.352963	-0.201233	-91.000530
958155	1578087.801	1149392.872	923.881	-0.421593	0.000588	90.878392
958156	1578083.364	1149758.335	923.720	0.384418	-0.048114	90.960789
958157	1578077.498	1150118.137	923.949	-0.650083	0.470542	-90.684502
958158	1578070.370	1150486.573	921.315	-0.902604	-0.412682	90.639181
958159	1578061.998	1150824.499	920.544	0.549016	0.303680	-90.262790
958160	1578051.238	1151189.756	920.203	0.248472	-0.372523	90.735208
958161	1578043.455	1151538.502	919.595	0.164688	-0.048049	90.863479
958162	1578036.650	1151903.137	916.488	-0.161114	0.072706	91.235011

Table 4.3. shows the coordinates for the control and pass points as well as the differences between the before and after triangulation.

Table 4.3. Coordinates of Control and Pass Points after Triangulation

Point #	Point Type	X'(M)	Y'(M)	Z'(M)	X'-X	Y'-Y	Z'-Z
2024	H	1577964.304	1148496.752	307.861	-0.632	-0.168	
2025	H	1578282.882	1148501.893	292.677	0.335	0.012	
2026	H	1578072.054	1148696.152	296.471	0.407	0.243	
2027	H	1578067.271	1149075.813	299.677	0.001	0.128	

2028	H	1578391.457	1149700.813	287.048	0.05 8	-0.2 10	
2029	H	1578064.524	1150324.876	286.873	-0.198	0.22 8	
2030	H	1578248.540	1151512.568	290.032	0.0 11	-0.700	
2031	H	1578051.782	1151586.671	288.633	0.089	-0.174	
2032	H	1578105.628	1151933.444	290.340	-0.07 1	0.642	
1029	V	1577861.353	1148486 190	310.208			0.154
1030	V	1578080.651	1148489.231	302.593			-0.223
1031	V						
1032	V	1578473.150	1148694.807	289.111			0.049
1033	V	1578075.901	1148975.457	298.641			0.073
1034	V	1577877.135	1149702.527	297.514			0.141
1035	V	1578021.375	1150108.613	287.717			-0.189
1036	V	1578325.633	1150117.600	287.672			-0.190
1037	V	1578057.520	1150921.022	287.640			0.211
1038	V	1578196.104	1151325.129	287.787			0.083
1039	V	1577862.704	1151726.038	290.578			-0.230
1040	V	1578217.868	1151733.865	288.796			0.121
			RMS in Meters:		0.203	0.220	0.1 63
3131		1577758 608	1148319.487	301.770			
3132		1578098.442	1148308.866	301.020			
3133		1578440.397	1148322.363	287.964			
3134		1578135.006	1148531.281	298.968			
3135		1577739.937	1148673.696	306.820			

3136		1578100.909	1148677.271	295.560			
3137		1578372.937	1148688.622	291.502			
3138		1578102.580	1148883.851	298.218			
3139		1577723.177	1149041.298	312.015			
3140		1578088.529	1149020.343	297.366			
3141		1578353.392	1149065.268	286.995			
3142		1578090.161	1149179.854	299.111			
3143		1577745.856	1149376.231	303.955			
3144		1578032.152	1149397.346	292.028			
3145		1578414.926	1149381.709	286.610			
3146		1578106.031	1149609.151	286.717			
3147		1577784.162	1149733.399	296.087			
3148		1578078.586	1149738.744	287.150			
3149		1578400.697	1149764.857	287.003			
3150							
3151		1577717.176	1150131.837	288.250			
3152		1578097.071	1150118.083	287.583			
3153		1578353.540	1150070.518	286.308			
3154		1578094.922	1150353.622	287.123			
3155		1577718.720	1150465.889	286.126			
3156		1578068.784	1150486.307	286.725			
3157		1578439.639	1150488.909	286.466			
3158		1578088.934	1150644.968	286.257			

3159		1577700.073	1150812.298	286.253			
3160		1578063.000	1150833.685	287.502			
3161		1578403.776	1150806.328	286.547			
3162		1578080.767	1151016.644	287.177			
3163		1577726.191	1151183.771	289.002			
3164		1578044.344	1151179.827	281.924			
3165		1578381.705	1151179.647	287.879			
3166							
3167		1577691.352	1151530.107	286.705			
3168		1577991.690	1151531.876	288.155			
3169		1578019.288	1151752.036	289.751			
3170		1578019.288	1151752.036	289.751			
3171		1577674.648	1151874.460	306.596			
3172		1578017.456	1151906.991	291.290			
3173		1578355.219	1151890.526	289.283			

4.1.3. Improving Ground Measurements and Triangulation

When the residuals of the triangulation indicate poor measurements, these measurements can be retaken. As mentioned before, measurement of the ground points is not done in three-dimensional view; therefore, remeasuring the ground points in the stereo pair from the first triangulation might improve the measurements and the triangulation.

Table 4.4. and Table 4.5. show the outputs after the ground points are double checked.

Table 4.4. Improved Triangulation Results

Photo No.	X(M)	Y(M)	Z(M)	$\omega(^{\circ})$	$\phi(^{\circ})$	$\kappa(^{\circ})$
958152	1578105.762	1148308.479	922.540	0.187743	-0.120827	-90.819390
958153	1578099.237	1148671.084	923.401	-0.108855	-0.386025	-90.642929
958154	1578092.724	1149035.541	924.138	-0.325396	-0.213154	-91.018041
958155	1578086.755	1149393.445	924.319	-0.461324	-0.088655	-90.909209
958156	1578082.228	1149758.756	923.893	-0.418918	-0.149668	-90.977311
958157	1578076.396	1150118.156	924.073	-0.651578	-0.573297	-90.674853
958158	1578068.660	1150486.566	921.516	-0.889192	-0.551802	-90.575426
958159	1578060.636	1150824.561	920.707	-0.547413	-0.388611	-90.197072
958160	1578051.270	1151193.517	919.828	-0.004569	-0.359636	-90.774483
958161	1578043.992	1151539.070	917.772	0.130072	-0.013889	-90.838147
958162	1578040.426	1151898.865	914.871	0.152680	0.152680	-91.275313

Table 4.5. Coordinates of Ground Points from Improved Triangulation

Point #	Point Type	X'(M)	Y'(M)	Z'(M)	X'-X	Y'-Y	Z'-Z
2024	H	1577964.939	1148496.896	307.334	0.003	-0.024	
2025	H	1578282.669	1148501.832	297.336	0.122	-0.049	
2026	H	1578071.723	1148695.989	295.848	0.076	0.080	
2027	H	1578067.006	1149075.790	300.034	-0.264	0.105	
2028	H	1578391.489	1149700.893	287.664	0.090	-0.130	

2029	H	1578064.675	1150324.653	286.748	-0.047	0.005	
2030	H	1578248.448	1151513.310	287.376	-0.081	0.042	
2031	H	1578051.780	1151586.828	287.566	0.087	-0.017	
2032	H	1578105.713	1151932.789	289.591	0.014	-0.013	
1029	V	1577861.368	1148484.101	310.054			0.000
1030	V	1578082.146	1148489.166	302.823			0.007
1031	V						
1032	V	1578473.323	1148694.841	289.068			-0.006
1033	V	1578075.626	1148975.433	298.557			-0.011
1034	V	1577877.123	1149702.616	297.372			-0.001
1035	V	1578021.433	1150112.504	287.908			0.002
1036	V	1578325.667	1150117.178	287.858			-0.004
1037	V	1578056.996	1150921.488	287.427			-0.002
1038	V	1578195.915	1151325.883	287.696			-0.008
1039	V	1577863.811	1151726.104	290.818			0.010
1040	V	1578216.176	1151731.922	288.677			0.002
			RMS in Meters:		0.072	0.042	0.004
3131		1577776.730	1148314.712	313.616			
3132		1578106.813	1148308.833	300.865			
3133		1578438.653	1148326.373	293.509			
3134		1578135.435	1148531.241	299.740			
3135		1577739.246	1148672.305	305.525			
3136		1578101.015	1148676.762	295.053			

3137		1578372.200	1148688.276	291.406			
3138		1578102.381	1148883.650	297.644			
3139		1577722.100	1149041.084	310.847			
3140		1578088.642	1149020.477	298.127			
3141		1578358.016	1149065.348	288.420			
3142		1578090.020	1149179.914	299.468			
3143		1577745.794	1149376.569	304.092			
3144		1578032.086	1149397.490	292.467			
3145		1578414.882	1149381.593	287.434			
3146		1578106.028	1149609.221	287.185			
3147		1577784.362	1149733.557	296.061			
3148		1578078.502	1149738.817	287.422			
3149		1578400.824	1149764.842	287.607			
3150							
3151		1577717.460	1150131.773	287.896			
3152		1578097.200	1150118.113	287.555			
3153		1578353.427	1150070.489	286.643			
3155		1577718.824	1150465.644	285.919			
3156		1578068.702	1150486.369	286.777			
3157		1578439.862	1150489.309	286.797			
3158		1578088.671	1150645.112	286.606			
3159		1577699.275	1150812.051	285.389			
3160		1578062.887	1150833.719	287.010			

3161		1578403.337	1150806.867	287.535			
3162		1578079.566	1151017.168	285.901			
3163		1577724.243	1151185.134	285.786			
3164		1578044.071	1151180.872	287.054			
3165		1578381.529	1151180.619	287.395			
3166							
3167		1577692.256	1151530.275	286.548			
3168		1577991.804	1151532.218	287.127			
3169		1578374.894	1151544.352	287.876			
3170		1578020.273	1151751.949	288.644			
3171		1577674.798	1151873.751	306.136			
3172		1578017.933	1151906.144	290.991			
3173		1578354.080	1151889.530	289.403			

After the remeasurement, the RMS decreased significantly, especially the RMS on the vertical controls, because the vertical controls do not have definite marks on the ground. Therefore, if the measurements are within a certain limit and the heights of these ground marks do not deviate from the known values, the only error source is a measurement for one control point that is not identical. This type of error can be detected by using the residuals from the triangulation results for each point.

Because the epipolar condition is also applied in the triangulation, the measurement errors in the pass points will also affect the triangulation results. Again, the residuals of the pass points can be used as a mean to remove the not-identical-spot problem, provided control measurements are good.

Because all of the following processes use the triangulation results, the quality of the triangulation is critical.

Table 4.6 RMS of the Difference

RMS of Differences @	X m	Y m	Z m	κ deg,	φ deg,	ω deg,
Pass Points	0.398	0.478	0.544			
Exterior Orientation	0.619	1.584	0.702	0.126	0.062	0.024

The table 4.6 shows the RMS of the difference for pass points and for the exterior orientation parameters from the aerial triangulation performed by Albany and SoftPlotter. The standard error of differences in coordinates less than 0.5 m is acceptable for setting the analogue stereoplotter. The main cause of the differences is the pugging of pass points on one photo resulting in misidentification on the others. Some of the differences were found to be larger than 1.5 m ($> 3\sigma$), due to this misidentification. If these points are not included, then the RMS will be much less.

The standard error of the aerial camera location is less than 1.5 m, and of the altitude angles less than 0.1 deg. This is acceptable for setting the stereo model in the analogue plotter. The standard errors vary because the Albany software only estimates exterior orientation parameters while in SoftPlotter the exterior orientation is part of the solution. Thus SoftPlotter should give better values of exterior orientation parameters than Albany.

4.2. Creation of TIN

The Digital Elevation Model (DEM) can be generated after the triangulation. In this project only triangular irregular network (TIN) is created. The TIN saves space because unlike DEM the elevations of every pixels are determined.

4.2.1. Stereo-rectification

After the triangulation, the exterior orientation parameters of each photograph in the strip are determined, so that two photographs can be rectified and resampled into the epipolar plane. This process is called "stereo-rectification" in SoftPlotter. After stereo-rectification, the images in the same area from

both photographs can be displayed and viewed three dimensionally. Because any point on the stereo display can be measured too, the ground coordinates of any point are available. The stereo-rectified photographs can also be used as the base images for creating DEM or TIN.

4.2.2. Generating the TIN

The parameters that need to be defined before creating the TIN are the output format and the ground spacing value. For the flat area, larger ground spacing can be used, but smaller ground spacing is needed for higher accuracy. The ground spacing used in the TIN is 8 meters. After the output TIN is given a name and the area of interest is defined, the TIN can be collected. Here only three models are used to create the TIN. They are from photographs No. 154, 155, 156, and 157.

4.2.3. Editing the TIN

Errors in the image matching can occur at any time. Some flat areas such as the top of buildings and the surfaces of bodies of water might have incorrect TINs. For some reason, the TIN on the edge of each model may also appear to be incorrect. However, the TINs can be edited by changing the heights of some points, putting some break lines along certain ground features, or setting the same height for certain areas like bodies of water.

4.2.4. Merging the TINs

Two or more TINs with common areas can be merged together so that the mean of all of the TINs in the common area can be used as their representative. The merged TIN is also useful for decreasing the distortion in the orthophoto, distortion caused by the difference among the TINs from different models of the common area.

Though the TIN merging function is not available in SoftPlotter, it has the ability to export the TIN in ASCII format so that it can be read by other software like Surfer on the PC. The procedure used to produce the merged TIN is as follows:

1. Export the TIN from Surface Tool in SoftPlotter as ASCII files. There are three such files because three models are used.
2. Use Microsoft Excel to merge these three files together and generate one output ASCII file.
3. Use Surfer in the merged ASCII file, and save it as an ASCII file in the same format as the file from Surface Tool.
4. Import the ASCII file from Surfer and generate the merged TIN in SoftPlotter.

The merged surface displayed by Surfer is shown in Figure 4.2. Now the common area looks considerably better.

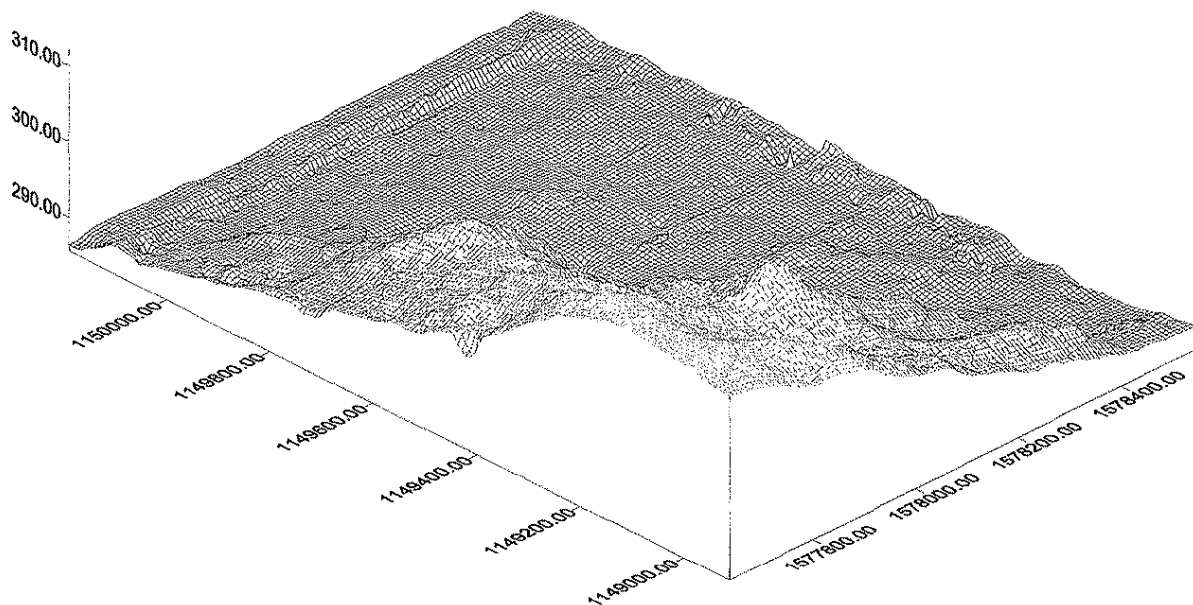


Figure 4.2. Surface of the Merged TIN

4.2.5. Generating the DXF Files of the Contours

Surfer also creates the contours. Figure 4.3. shows the contour lines of this area at contour intervals of 1 meter.

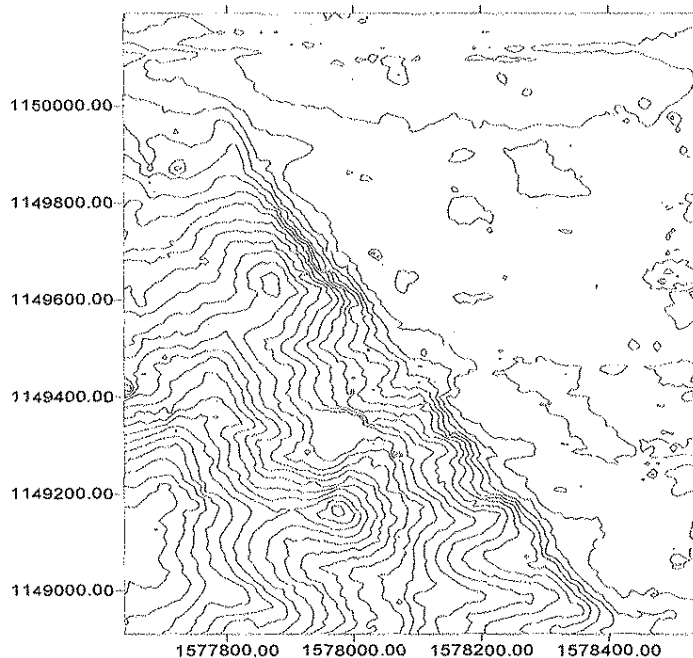


Figure 4.3. 1 M C.I. the Merged TIN

These contour lines are satisfactory. On the contour map, the outline of a small pond can be seen; there is no contour line through that area. The coordinates marked on the preceding two figures are in the real-world coordinate system, IA north of state plane coordinate system.

The accuracy of these contours is better than 0.5 m. Using the surface and merged files, profiles and cross sections can be created. The relative accuracy of such profiles and cross sections should be better than 0.1 m, which is acceptable for highway engineering. Using Arc/Info software, these contours were compared with those by the IA DOT. (See Figures 4.4. and 4.5.) In the hilly area, Figure 4.4., they agree well but in the the flat area, Figure 4.5., the agreement is only fair because of the error in the automatic matching. In the areas with buildings, the contours by the IA DOT give ground level contours,

while in SoftPlotter the matching is done on the top of the building, which is the feature that is photographed.

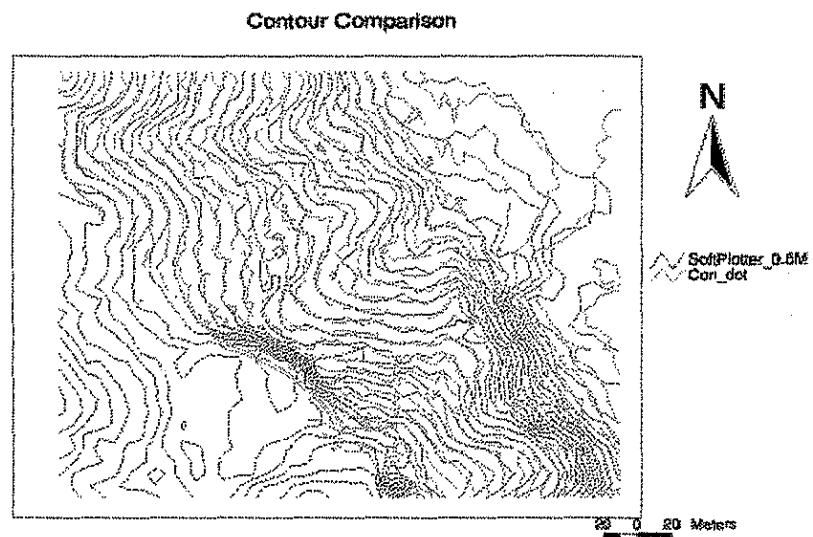


Figure 4.4.

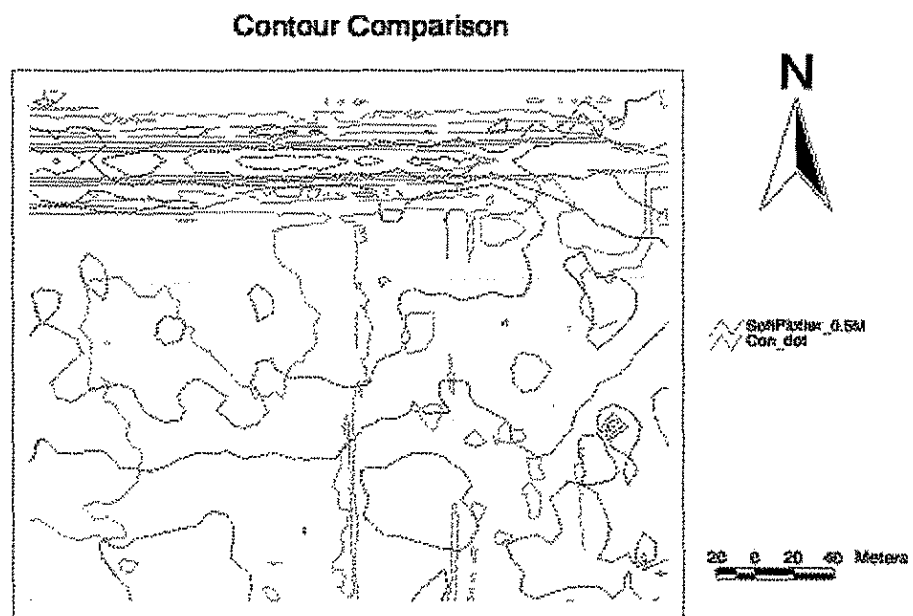


Figure 4.5.

4.3. Creating Orthophotos and Mosaicing

Once the TIN is created, the orthophoto can be obtained from the TIN and the photographs.

4.3.1. Generating Orthophotos

The orthophoto can be generated using the Ortho Tool in SoftPlotter. Since the merged TIN of the three models is available from the previous section, the orthophotos are created from the merged TIN. For these three models, only two separate orthophotos need to be generated. Photo No. 155 is used to generate the orthophoto from models 154/155 and 155/156; photo No. 156 is used to generate the orthophoto from model 156/157. Figures 4.6. and 4.7. show these orthophotos.



Figure 4.6. Orthophoto from Model 154/155, 155/156



Figure 4.7. Orthophoto from Model 156/157

4.3.2. Mosaicing

To mosaic the three models together, the geometric and radiometric distortion must be considered. Because they are from different photographs in the stereo pair, the same location can have different radiometric values. The same location on the ground may have different radiometric values in each photograph because a geometric difference exists between different TINs in the common area. The radiometric difference between the photographs in the stereo pair also makes the same location on the ground have different radiometric values. Since the merged TIN has been obtained from the previous section, the geometric distortion has been decreased to a minimum. The merged TIN also helps to decrease the radiometric distortion between models on the orthophoto because the number of orthophotos in the mosaicing process is halved. In the SoftPlotter mosaicing tool, the feathering technique is used to smooth the borderline between two contiguous orthophotos. Therefore, the difference on radiometric values is small and harmonious on the mosaicing. Figure 4.8. shows the mosaicing output.



Figure 4.8. Mosaicing of the Three Models

4.4. Digitizing Tool: KDMS

KDMS Tool is a third-party SoftPlotter software that can be used to do 3-D digitizing. In the KDMS Tool, different types of ground features are assigned different code numbers so that they can be

placed in different layers. The digitized data can then be saved in a KDMS file, or they can be exported as a DXF file or Arc/Info file.

In this project, four types of ground features are digitized: fence lines, buildings, roads, and ponds. These features were compared with the Kern PG2 plotted maps (see Figures 4.9.) and found to be satisfactory. Therefore this tool can be used in highway engineering.

4.5. GIS Application and Map Making

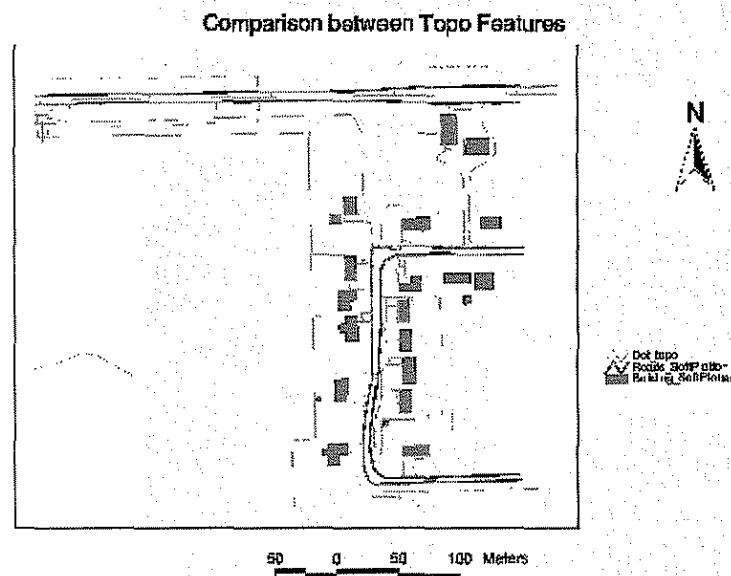


Figure 4.9 Comparison of Softplotter with Kern PG2

Arc/Info and ArcView are used in this GIS application, and all of the spatial data from SoftPlotter and Surfer will also be used.

There are three coverages from the KDMS tool. Arc/Info is used to process these coverages, construct the topology, and import the contour map in DXF format from Surfer. The orthophoto is also registered in Arc/Info. After all of these process are completed, ArcView is used to display the map.

(See Figure 4.10.) Thus Arcview and the base maps produced by SoftPlotter maps can be used in highway engineering.

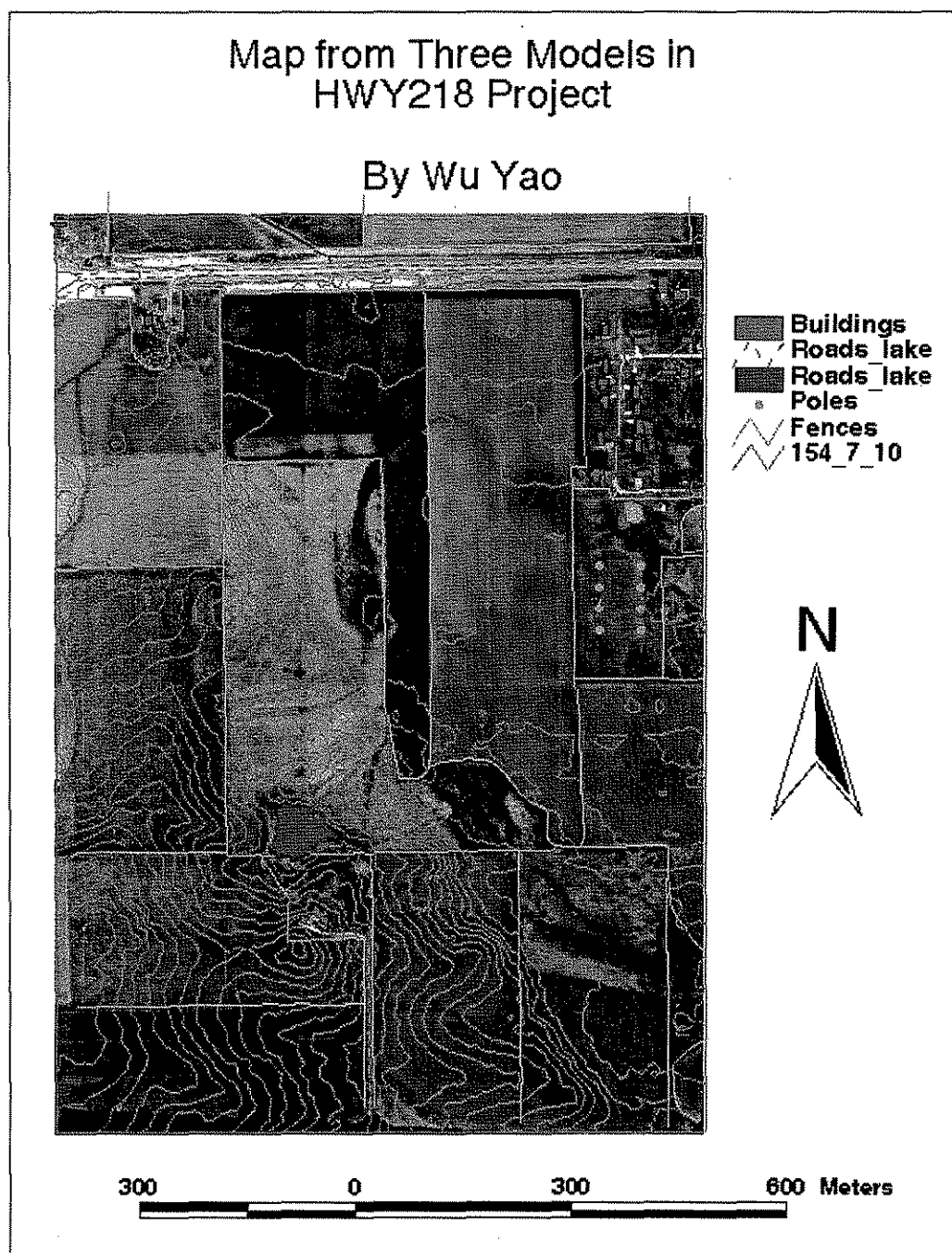


Figure 4.10. Map Made with ArcView

4.6. Feasibility of Transferring the Technology

An advising committee consisting of Alice Welsh (IA DOT Photogrammetric Engineer), Marlee Walton (IA DOT Maintenance Engineer), Don Callender (City Engineer), and Steve DeVries (County Engineer) was formed. The technology was demonstrated to these members. Appendix F provides information about this technology.

Jeff Danielson, a senior technical staff member of IA DOT who works with the analytical plotter, was trained on SoftPlotter for two days. He is able to do the 11 photo aerial triangulations satisfactorily.

Jean Borton, who works with Kern PG2 at the IA DOT, was trained on SoftPlotter for three days. She is able to plot a stereo pair using KDMS. Again, for more information, see Appendix F.

CHAPTER 5. FUTURE APPLICATIONS OF SOFT PHOTOGRAMMETRY

Unlike analogue and analytical photogrammetry, soft photogrammetry has many applications. Mapping using low-flight aerial photography and video terrestrial photographs are two applications that are useful in highway engineering. The objective of this chapter is to describe the two projects, helicopter and video logging, used to study these soft photogrammetry applications. Another newer, rapidly developing technology is virtual reality. It uses spatial data to create three-dimensional (3-D) views from different locations in different directions in real time. It will be useful in highway engineering for 3-D designing and verification.

5.1. Helicopter Project

One of the problems facing U.S. departments of transportation is making improvements to existing highway systems within cities. Plans of the existing corridors have to be done on a large scale such as 1 inch = 20 ft or 1:200. To produce topographic maps on a scale of 1 inch = 100 ft, photographs at a scale of 1 inch = 250 ft or a flying height of 1,500 ft are used. To produce maps at 1 inch = 20 ft, photographs at 1 inch = 50 ft or a flying height of 300 ft are required. Unfortunately, the Federal Aviation Administration (FAA) restricts aircraft flying height to about 500 ft within cities. To overcome this constraint, an alternate platform, a helicopter, is currently being explored.

Low-altitude photography is not suitable for use with analogue stereoplotters. Analogue stereoplotters are designed to work with ground undulations of about 10% of the flying height, which is not possible to maintain at low-altitude flying, and with tilt angles less than 5%, which are not always possible with helicopters. However, soft photogrammetry can be used with low-altitude photography without serious limitations.

In this research, we used a strip of helicopter photographs over Highway 235 near Des Moines, Iowa, to conduct an aerial triangulation as well as create a stereo model, Digital Elevation Model (DEM), and orthophoto for pairs of models.

5.1.1. Aerial triangulation

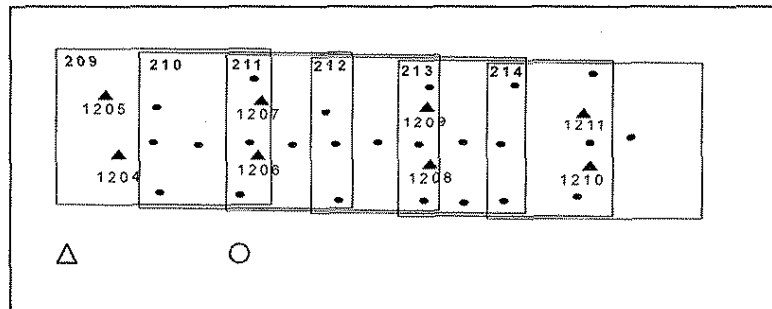


Figure 5.1. Control (Δ) and Pass (\circ) Points for a Strip of Six Photos (209 to 214)

Figure 5.1. is the layout diagram of a strip of six photographs taken over Highway 235 at a flying height of 300 ft using a helicopter fitted with a wide-angle camera. It shows the control points and pass points. The objective is to determine the coordinates of the pass points using the control points. The relative accuracy of the control points is about ± 2 cm and the accuracy required for 1 inch = 20 ft scale map is about 10 cm. Therefore, the accuracy is ± 5 cm. The pass point coordinates are sufficient for the production of the orthophoto at 1 inch = 20 ft and for the profile and cross-section plotting.

To create the digital data, the photographs are scanned using an HP Scanjet JC at 300 dpi (dots per inch). The size of the pixel at 300 dpi is about $48 \mu\text{m} \times 48 \mu\text{m}$ or about 3 cm x 3 cm at ground scale when the scale of the photograph is 1 inch = 50 ft, resulting in digital files of 2,000 Mb. Since the cursor is about $25 \mu\text{m}$, pointing error on the center of the pixel is about $\pm 1 \mu\text{m}$. Thus, the HP Scanjet provides the accurate digital data required for this triangulation.

One of the first steps in aerial triangulation is to perform the interior orientation using the fiducial marks in the photographs. The coordinates of the fiducial are known to be $\pm 1 \mu\text{m}$ from the camera calibration. The interior orientation using orthogonal transformation produced a root mean square (RMS) of 0.05 mm. The RMS error indicates a distortion error due to film shrinkage, a print error due to scanning, and a measurement error. As mentioned earlier, an error of 0.05 mm is acceptable for this triangulation.

As before, the coordinates are measured simultaneously on the three digital images using monovision. The points are identified using real-time enlargement, contrast, and brightness. Since the resolution is about 50 μm , some of the ground control targets on asphalt are hard to identify. Perhaps 600 or 400 dpi will help to identify the targets better, which means large storage, the use of a larger computer, etc.

Table 5.1. shows the control point coordinates obtained from aerial triangulation by SoftPlotter and ground survey (Albany). For the helicopter photograph, the RMS of the difference in x, y, and z between the SoftPlotter aerial triangulation and the ground survey is about 3 cm. This is acceptable for 1 inch = 20 ft mapping.

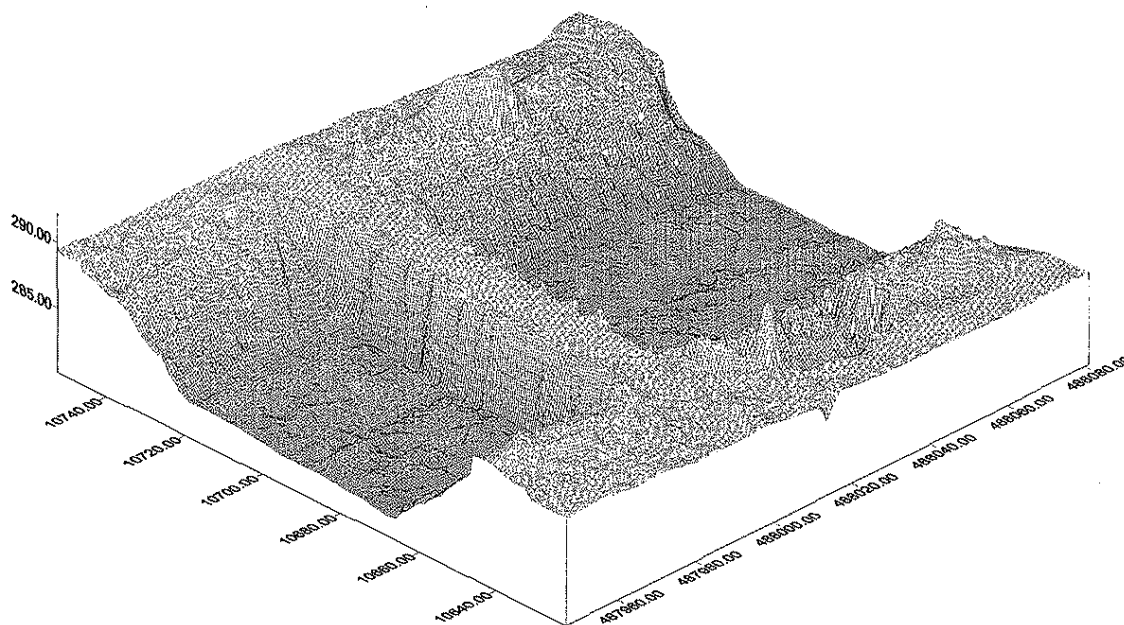
Table 5.1. Control Point Coordinates from SoftPlotter and Albany

Point No.	Point Type	From SoftPlotter			From Albany		
		$X(m)$	$Y(m)$	$Z(m)$	X	Y	Z
1204	C				487956.322	177206.229	281.572
1205	C	487936.843	177261.679	283.300	487936.856	177261.699	283.301
1206	C	488047.110	177209.188	281.417	488047.068	177209.183	281.382
1208	C	488156.367	177208.200	279.567	488156.429	177208.156	279.633
1210	C	488265.852	177205.563	277.448	488265.846	177205.577	277.418
1211	C	488265.391	177257.792	277.339	488265.364	177257.807	277.337
		For X	For Y	For Z			
RMS		0.036	0.023	0.036			

5.1.2. DEM and Orthophoto

The exterior orientation elements of the photograph obtained by aerial triangulation are then used by SoftPlotter to rectify the photograph and convert the model coordinates to epipolar coordinates for good stereo viewing. The Surface Tool in SoftPlotter automatically obtains the DEM for the model area, using the auto correlation technique. Because the terrain undulation is more than 10% of the flying

height, the automatic DEM has to be manually edited with care. This manual editing is performed by checking the bad points indicated by the software and then by creating and viewing the automatic contours. Where the contour does not agree with the terrain, the points and areas are manually edited. Each model's DEM is then joined together using the PC software, Surfer. Figure 2 shows the ground surface created from the two models. The surface clearly shows the overpass and the embankment. Therefore, preliminary design can be done directly on the 3-D surface either in Surface Tool or in Surfer. Again, the surface shows the large ground undulation, which causes problems in automatic image matching.



from the center of the photograph, where H is the flying height and dh is the undulation. For this altitude, it was necessary to create DEM at 1/2 m grid intervals, which means large volumes of data; the manual editing of these data would require a great deal of time. Figure 5.3. shows an orthophoto that needs some manual editing at the edge of the overpass. Figure 5.4. shows an orthophoto in which most of the manual editing is done. The accuracy of the orthophoto is expected to be ± 10 cm and the resolution is about 5 cm, which is good for 1 inch = 20 ft mapping. Since the typical resolution of aerial cameras is about 1 to 2 cm (which is the practical limit possible), the resolution of the orthophoto can be improved by using higher dpi scanners.

A view of the orthophoto in Figure 5.4. clearly indicates that it can be used for designing highway improvements; further, by using high-resolution scanners, the orthophoto's resolution will be two to three times better. However, higher resolution scanners will not necessarily improve the geometric accuracy but will increase the storage space by four to nine times.

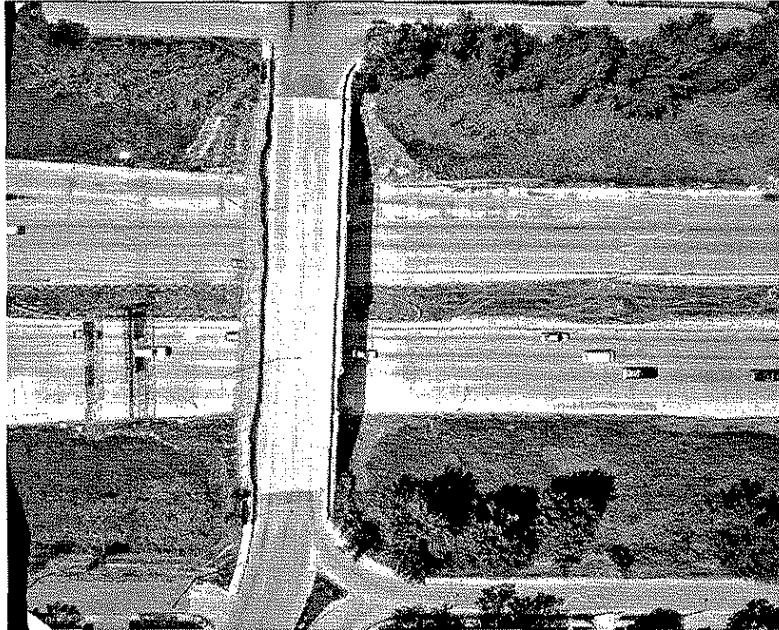


Figure 5.3. Orthophoto



Figure 5.4. Edited Orthophoto

5.2. Video Logging Images for As-built Survey and Monitoring Road Conditions

The Iowa Department of Transportation takes video images every 25 ft along primary and secondary roads, using a van equipped with two video (digital) cameras and a differential phase code global positioning system (GPS) receiver (see Figure 5.5.).

Soft photogrammetry can be used to create a stereo model from these digital images, provided the digital cameras are calibrated. Measurements on the stereo model can be used to obtain X, Y, and Z coordinates or stations, perpendicular offsets, and elevations of points along the roads. This information can be used to plot the "as-is" plans, profiles, and cross sections. Photo 5.6. shows the target setup used to calibrate the video cameras. Table 5.1. shows the results of the calibration. Photo 5.7. shows a video imagery along a secondary road, and Figure 5.8. shows the plan obtained by soft photogrammetry.

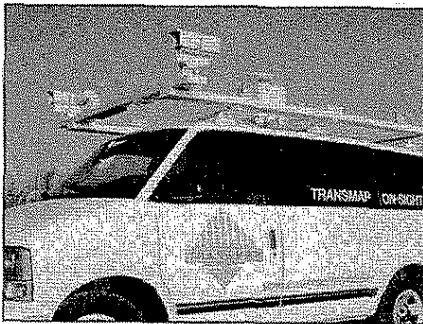


Figure 5.5. Van with Video Camera and GPS Receiver



Figure 5.6 Calibration Targets for Video Camera



Figure 5.7 Video Imagery of Secondary Road

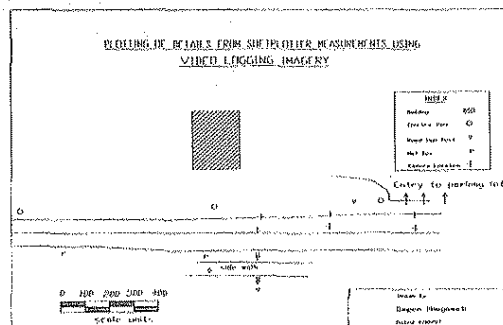


Figure 5.8 Plotted Details from SoftPlotter Measurements

Soft photogrammetry can also be used to monitor road conditions using the radiometric values (gray scales) recorded by the video camera. Figure 5.11. shows the black and white image of a color video image. The Imagine, an image analysis software in soft photogrammetry, is then used to classify road conditions. Figure 5.9. shows the area selected for classification, and Figure 5.10. shows the details of the road conditions after classification. Figure 5.10. and the related radiometric values can be used to monitor the road conditions. The location of the area can be determined from the stereo model and the GPS data.

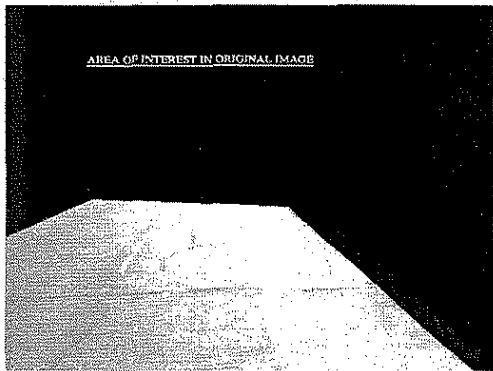


Figure 5.9. Area of Interest in the Original Image

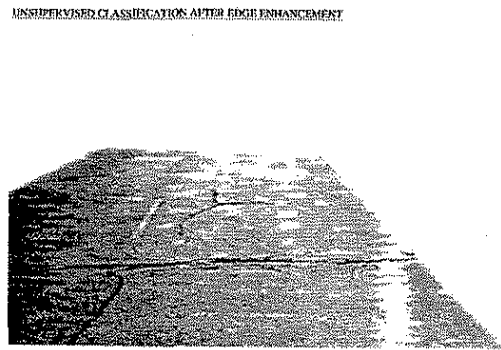


Figure 5.10. Unsupervised Classification after Edge Enhancement

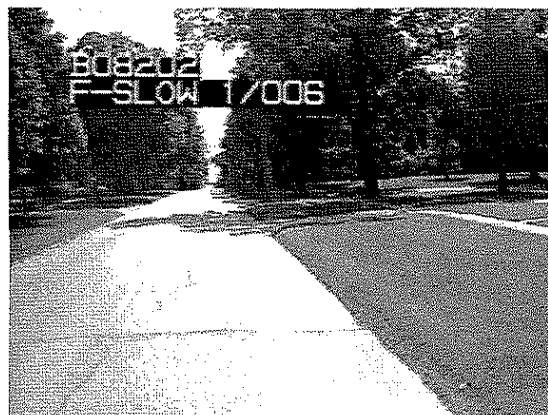


Figure 5.11. Original Imagery

Table 5.2 Calibration of Video Cameras

INPUT DATA FOR BLOCK

7
 24.515 24.515
 2.555 2.555
 11.370 11.370
 0.000 0.000
 0.000 0.000
 0.000 0.000

5
 29.920 29.920
 2.550 2.550
 38.330 38.330
 0.000 0.000
 0.000 0.000
 0.000 0.000

1 RESIDUAL AND OBSERVATION EQUATION BEFORE 1ST CYCLE

S.NO.	PT.NO.	RES. IN X	RES. IN Y
1	1	-126.557	111.447
2	3	-154.280	106.666
3	7	-151.914	84.626
4	9	-132.298	99.096
5	10	-160.330	95.751
6	15	-142.089	116.404
7	18	-140.904	102.660
8	2	-176.575	98.724
2	3	-187.013	100.514
9	6	-175.135	86.261
6	15	-164.799	112.089
7	18	-162.444	103.476

INTERIOR ORIENTATION PARAMETERS

0.48978E-05 -0.43389E-05 -0.67630E+03 -0.42784E-04 -0.38900E-05 -0.41242E-06 -0.38149E-06 0.33371E-12 0.12011E-24

ICYCLE= 4 VARIANCE= 0.227540E+00 NDF= 12

CAMERA CALIBRATION OF THEVI_right SS 1997
 NO. OF PHOTOS. 2
 NO. OF CONTROL POINTS. 9
 DEGREES OF FREEDOM. 12
 NO. OF CYCLES. 4
 VARIANCE OF UNIT WEIGHT= 0.22867E+00

RESULTS INTERIOR ORIENTATION

	X	Y	F	K1*10**-6	K2*10**-12	K3*10**-18	P1*10**-6	P2*10**-12	P3*10**-18
	0.0000048	-0.0000043	-676.299	-0.000043	-0.000004	0.000000	0.000000	0.000000	0.000000
STD.	0.151E-01	0.151E-01	0.151E-01	0.478E-02	0.478E-02	0.478E-02	0.478E-02	0.478E-02	0.478E-02
WEIGHT	0.100E+04	0.100E+04	0.100E+04	0.100E+05	0.100E+05	0.100E+05	0.100E+05	0.100E+05	0.100E+05

EXTERIOR ORIENTATION

PHOTO NO. 1- 0	XO	YO	ZO	KAPPRAD.),1	PHI(RAD.)	OMEGA(RAD.)
	24.283183	1.910004	7.755757	-0.012973	-0.213760	-0.153167
STD.ERROR	0.358108	0.486095	1.164520	0.040415	0.009784	0.009845
WEIGHT	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

RESIDUALS ON CONTROL POINTS (PHOTOCO-ORDINATE UNITS)

S.NO.	POINT NO.	X-COORDINATE	Y-COORDINATE	Z-COORDINATE	RESIDUALS IN X	RESIDUALS IN Y
1	1	28.706	-2.051	-8.216	0.000006	0.000001
2	3	22.530	-1.639	-7.225	0.000030	-0.000025
3	7	23.771	-4.295	-7.108	0.000023	-0.000024
4	9	31.350	-3.880	-32.929	0.000009	-0.000030
5	10	21.239	-3.765	-31.251	-0.000028	-0.000038
6	15	29.558	4.467	-71.975	0.000011	0.000190
7	18	29.536	-5.806	-72.079	0.000018	-0.000163

EXTERIOR ORIENTATION

PHOTO NO. 2- 0	XO	YO	ZO	KAPPRAD.),1	PHI(RAD.)	OMEGA(RAD.)
	31.583984	3.601993	38.727395	-0.021737	-0.220170	-0.167621
STD.ERROR	0.644952	0.698797	1.617853	0.040664	0.010567	0.009170
WEIGHT	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

RESIDUALS ON CONTROL POINTS (PHOTO CO-ORDINATE UNITS)

S.NO.	POINT NO.	X-COORDINATE	Y-COORDINATE	Z-COORDINATE	RESIDUALS IN X	RESIDUALS IN Y
8	2	25.877	-1.305	-7.409	0.000027	0.000003
2	3	22.530	-1.639	-7.225	-0.000040	0.000008
9	6	25.827	-5.098	-7.444	0.000027	-0.000045
6	15	29.558	4.467	-71.975	-0.000004	-0.000165
7	18	29.536	-5.806	-72.079	0.000004	0.000163

5.3. Integration of Soft Photogrammetry and Virtual Reality

Soft photogrammetry is the science of making measurements in three dimensions using stereo digital imagery. The advent of computer technology has facilitated its development. Soft photogrammetry is mainly used in topographic mapping from aerial photographs. Figure 5.12. shows the surface polygon developed by soft photogrammetry, Figure 5.13. shows the topographic information produced by soft photogrammetry for Geographic Information System, and Figure 5.14. shows the Silicon Graphics workstation set up for soft photogrammetry,

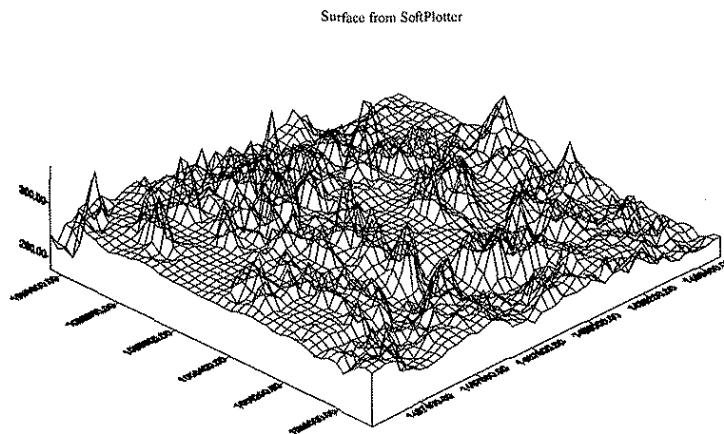


Figure 5.12.

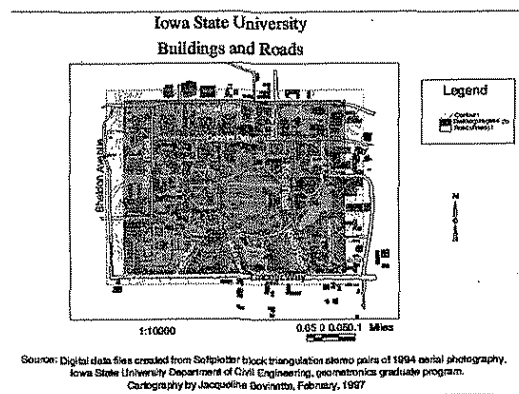


Figure 5.13.



Figure 5.14. SoftPlotter TM on Silicon Graphics Workstation

5.3.1. Virtual Prototyping

Virtual reality is the science of using polygons to view an item in three dimensions from any location and direction. According to Howard Rheingold, it is “an experience in which a person is surrounded by a three-dimensional computer-generated representation and is able to move around in the virtual world and see it from different angles, to reach into it, grab it and

reshape it.” See Figures 5.15. and 5.16. Here too, computer technology has facilitated its development. Currently this is mainly used in virtual prototyping.

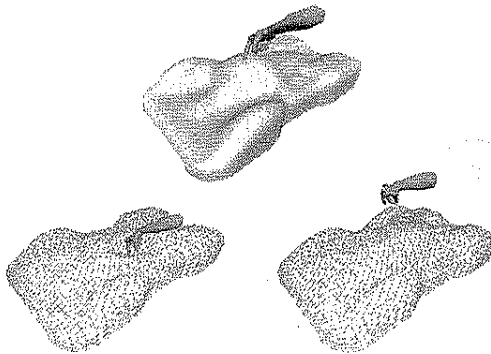


Figure 5.15. The world of Virtual Reality

5.3.2. Virtual Reality Environment

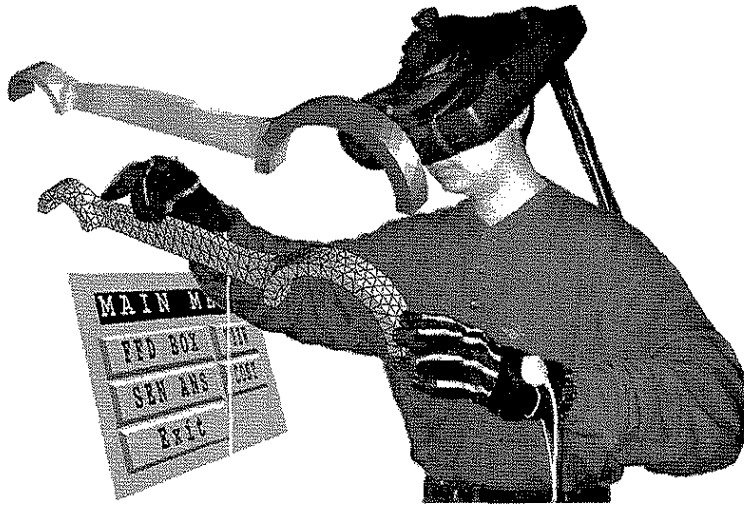


Figure 5.16. A Virtual Reality Environment

Currently both technologies use 200-Hz Silicon Graphics computers with 2 to 4 Gb of disk space. Thus both technologies are computation intensive. Soft photogrammetry can be used to obtain the 3-D spatial data required to create polygons in virtual reality. See Figures 5.12. and 5.15. In soft photogrammetry, a 3-D view is obtained from one location and in one direction, while in virtual reality, it is possible to get a 3-D view from any location and direction. It appears that integration of the two technologies will contribute to the development of both.

CHAPTER 6. CONCLUSION AND RECOMMENDATION

In many aspects, soft photogrammetry is now an improvement on analytical photogrammetry. SoftPlotter, the soft photogrammetric software used in this study, is comparable or better than other currently available software such as Integraph and Socket. It now uses Silicon Graphics and Unix workstations. The TNT mips, a PC software that does not have stereo vision capability, is therefore not comparable to SoftPlotter. Computer technology is advancing rapidly and software such as SoftPlotter should be able to use the PC window NT in the near future. When compared to Silicon Graphics, the PC is cheaper and most users are already familiar with its operations.

The Campus Project demonstrated that soft photogrammetry is accurate for all aspects of traditional photogrammetry and can also be used for producing large-scale orthophoto and base maps for Geographic Information System (GIS) applications. The project showed that flatbed scanners with 300 dots per inch (dpi) to 600 dpi give sufficient geometric accuracy for use in soft photogrammetry.

The Highway Project demonstrated that soft photogrammetry is accurate for highway engineering applications. The project showed that the technical staff at the Iowa Department of Transportation (IA DOT) can be easily trained in this technology. Highway, county, and city engineers who are on the advisory committee for this study also felt that this technology is useful for many aspects of civil engineering and can be easily transferred. This project also showed that the drum scanner of 900 dpi provides sufficient geometric accuracy for soft photogrammetry.

The Helicopter Project demonstrated that soft photogrammetry can be used for low-flight, large-scale mapping; the Video Logging Project showed that soft photogrammetry can be adopted for inventory and GIS studies.

With research, virtual reality can be used in the three-dimensional (3-D) designing of highways and subdivisions. Soft photogrammetry can be used to collect the spatial coordinates of the polygons used in virtual reality.

6.1. Recommendation

We recommend that IA DOT use soft photogrammetry for producing orthophoto and base maps for GIS applications.

Analytical stereoplotters, because of their accuracy and versatility, will be in demand for years to come. However, the analogue stereoplotters will be off the market mainly because of their cost and their requirement for skilled operators. We therefore recommend that analogue stereoplotters be phased out and replaced by soft photogrammetry.

Helicopter photography with soft photogrammetry is recommended for large-scale mapping. Research is needed to develop methods to calibrate digital cameras so that they can replace the aerial cameras in helicopter photography.

We also recommend that a flatbed scanner of 750 dpi to 1,000 dpi with a 23 cm x 23 cm format be developed. Such a scanner is geometrically accurate for most highway engineering applications.

Video logging is currently used in highway maintenance. We recommend that research be conducted to use video imagery with soft photogrammetry for inventory and GIS studies. Also, research on automatic feature extraction should be performed. Finally, we recommend that research be conducted to develop methods of integrating soft photogrammetry and virtual reality. Virtual reality will lead to the 3-D designing of highways and subdivisions.

7. ACKNOWLEDGMENT

The authors wish to thank the Iowa Highway Research Board for supporting this research project. In particular we wish to thank George Sisson and Mel Nutt of the Iowa Department of Transportation (IA DOT) for their continued support of education and research in surveying at Iowa State University (ISU). Thanks are also due to Vernon Marks of the IA DOT for his assistance in completing this project.

Special thanks are due to the following advisory committee members for making time to attend committee meetings and for giving advice and support to this research: Don Callender, Steve DeVries, Marlee Walton, and Alice Welsh. Thanks are due to Jeff Danielson, Sheri Anderson, Andrew Short, and Gene Burton of the IA DOT for participating in this research. Special thanks are due to Susan Warner of the University of Osteopathic Medicine, Des Moines, IA.

Our thanks also goes to Vision International Inc., Leica Inc., Integraph Inc., and TNTMips Inc. for the opportunity to use their software, and to a number of graduate students—Charles Bernard, Rufeng Xi, Kang, and Sarathchandra—for their help on this project. Thanks are due to Transmap Inc. for providing the video logging images.

Finally, we also wish to thank Dr. Lowell Greimann, Chairman, and the staff of the Department of Civil Engineering; Dean James Melsa; Associate Dean Ted Okiishi; the staff of the Engineering Research Institute; Dr. Judy Vance of the Department of Mechanical Engineering for information and a demonstration of the virtual reality system; and ISU for their assistance in getting this project completed on time.

8. BIBLIOGRAPHY

- Ackermann, F., 1996, "Techniques and Strategies for DEM Generation," *Digital Photogrammetry*, American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland, pp 135 -141.
- Ackermann, F., 1984, "Digital Image Correlation: Performance and Potential Application in Photogrammetry," *Photogrammetric Record*, 11 (64), pp 429 - 439.
- Ackermann, F., 1983, "High Precision Digital Image Correlation," Proceeding 39th Photogrammetric Week, pp 231 - 243.
- Ackermann, F., and Schneider W., 1986, "High Resolution Aerial Triangulation with Point Transfer by Digital Image Correlation," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 26, Commission III, pp 18 - 27.
- Ackermann, F., and Schneider W., 1986, "Empirical Investigation into the Precision of Digital Image Correlation," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 26, Commission III, pp 115 - 130.
- Adamos, C., and Faig W., 1992, "Hough Transform in *Digital Photogrammetry*," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 28, Commission III, pp 250 - 254.
- ARC/INFO, Version 7.0 1995, Online Help Manual Environmental Systems Research Institute, Redlands, CA.
- Al-Tahir, R., and Schenk T., 1992, "On the Interpolation problem of Automated Surface Reconstruction," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 28, Commission III, pp 227 - 232.
- Balce, A. E., 1986, "Determination of Optimum Sampling Interval in Grid Sampling of Digital Elevation Models for Large Scale Application," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 26, Commission III, pp 40 - 54.
- Benard, M., Boutaleb A. K., Kölbl O., and Penis C., 1986, "Automatic Stereophotogrammetry: Implementation and Comparison of Classical Correlation Methods and Dynamic Programming Based Techniques," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 26, Commission III, pp 131 - 140.
- Benard, M, 1984, "Automatic Stereophotogrammetry: A Method Based on Feature Detection and Dynamic Programming," *Photogrammetria*, Vol 39, pp 169 - 181.
- Bertram, S., 1963, "Automatic Map Compilation System," *Photogrammetric Engineering*, Vol 29 (4), pp 675 - 679.

Bethel J. S., and Mikhail E. M., 1984 "Terrain Surface Approximation and On-line Quality Assessment," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 25 (A 3a), Commission III, pp 23 - 32.

Blachut T. J., and Burkhardt R., 1989, "Historical Development of Photogrammetric Methods and Instruments," American Society of Photogrammetry and Remote Sensing, 1989.

Boniface, P. R., 1996, "State-of-the-art in Soft Copy Photogrammetry," *Digital Photogrammetry*, American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland, pp 227 - 229.

Boochs, F., 1992, "Object Space Based Correlation with Additional Information," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 28, Commission III, pp 127 - 132.

Boochs, F., 1987, "Off-line Compilation of Stereo Models Using Digital Image Correlation," *Photogrammetria*, 41, pp 183 - 199.

Boochs, F., 1986, "Determination of A Digital Terrain Model from Space Metric Camera Pictures by Means of Digital Image Correlation," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 26, Commission III, pp 79 - 22.

Bouchard, R. H., 1988, "Optimized Observation Periods Required to Achieve Geodetic Accuracies Using the Global Positioning System," M. S. Thesis, Naval Postgraduate School, Monterey, California.

Brown, R. G., Jeyapalan K., and Rector J., 1985, "Use of Global Positioning System for Precise Relative Positioning and Land Surveying," Final Report, Iowa High Technology Council.

Cho, W. S., and Schenk T., 1992, "Resampling Digital Imagery to Epipolar Geometry," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 28, Commission III, pp 404 - 408.

Claus, M., 1984, "Digital Terrain Model through Digital Stereo Correlation," *Photogrammetria*, 39, pp 183 - 192.

Church, E., 1942 - 1948, "A Series of Bulletins on Aerial Photogrammetry," No. 13 - No. 19, Syracuse University.

Day, T., 1989, "DEM Production by Stereo Matching SPOT Image-pairs: A Comparison of Algorithms," *Image and Vision Computing*, 7 (2), pp 95 - 101.

Diehl, H., and Heipke C., 1992, "Surface Reconstruction from Data of Digital Line Cameras by Means of Object Based Matching," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 28, Commission III, pp 287 - 294.

Ding, M. Y., 1992, "The Evaluation of Acquisition Probability in Image Matching," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 28, Commission III, pp 375 - 378.

- Dowman, L. J., 1984, "Problems and Some Solution in Digital Correlation for Photogrammetric Profiling," *Photogrammetria*, 39, pp 155 - 167.
- Ehlers, M., and Welch R., 1987, "Stereo Correlation of Landsat TM Image," and Remote Sensing, Vol 53 (9), pp 1231 - 1237.
- Ehlers, M., 1985, "The Effects of Image Noise on Digital Correlation Probability," *Photogrammetric Engineering and Remote Sensing*, Vol 51 (3), pp 357 - 365.
- El-Hakim, S. F., 1989, "A Hierarchical Approach to Stereo Vision," *Photogrammetric Engineering and Remote Sensing*, Vol 55 (4), pp 443 - 448.
- Ellis, S., 1994, "What are Virtual Environments?," *IEEE Computer Graphics and Applications*, Vol 14 (1), pp 17 - 22.
- ERIO Technologies, 1991, "MAP/PAL/ALBANY User's Manual," 800 Sunrise Avenue, Suite C, CA 95661. Telephone 916-782-6671.
- Faintich, M. B., 1984, "State-of-the-art and Future Needs for Developments of Digital Terrain Models," *ISPRS International Archives of Photogrammetry and Remote Sensing*, Vol 25, (A 3a), Commission III, pp 180 - 196.
- Fallvik, J. O., 1986, "Image Restoration Methods as Preprocessing Tools in Digital Stereo Matching," *ISPRS International Archives of Photogrammetry and Remote Sensing*, Vol 26, Commission III, pp 223 - 235.
- Förstner W., and Gülch E., 1987, "A Fast Operator for Detection and Precise Location of Distinct Points, Corners and Centres of Circular Features," *ISPRS Intercommission Conference on Fast Processing of Photogrammetric Data*, Interlaken, Switzerland, June, pp, 281 - 305.
- Förstner, W., 1986, "A Feature Based Correspondence Algorithm for Image Matching," *ISPRS International Archives of Photogrammetry and Remote Sensing*, Vol 26, Commission III, pp 150 - 163.
- Förstner, W., 1984, "Quality Assessment of Object Location and Point Transfer Using Digital Image Correlation Techniques," *ISPRS International Archives of Photogrammetry and Remote Sensing*, Vol 25 (A 3a), Commission III, pp 197 - 219.
- Förstner, W., 1982, "On the Geometric Precision of Digital Correlation," *International Archives of Photogrammetry and Remote Sensing*, Symposium Helsinki, Commission III, Vol 24, (3), pp 176 - 189.
- Frederiksen, P., and Jacobi, O., 1986, "Optimal Sample Spacing in Digital Elevation Models," *ISPRS International Archives of Photogrammetry and Remote Sensing*, Vol 26, Commission III, pp 252 - 259.
- Frederiksen, P., Jacovi, O., and Kubik, K., 1985, "A Review of Current Trade in Terrain Modelling," *ITC Journal*, 1985-2, pp 101 - 106.

Fukushima Y., 1988, "Generation of DTM using SPOT Image Near Mt. Fuji by Digital Image Correlation," *International Archives of Photogrammetry and Remote Sensing*, Vol 27, Commission III, pp 252 - 259.

Goung, L., and Zheng, T., 1992, "Stereo Matching Using Artificial Neural Networks," *ISPRS International Archives of Photogrammetry and Remote Sensing*, Vol 28, Commission III, pp 417 - 421.

Greenfeld, J. S., 1990, "An Automatic Relative Orientation Based on Computer Vision Principles," *Proceedings of 1990 ACSM-ASPRS Annual Convention*, Vol 5, pp 34 - 43.

Greenfeld, J. S., 1988, "Stereo Matching without An Operators's Intervention," *Proceedings of 1990 ACSM-ASPRS Annual Convention*, Vol 3, pp 56 - 65.

Greenfeld, J. S., and Schenk, A. F., 1989, "Experiments with Edge-Based Stereo Matching," *Photogrammetric Engineering and Remote Sensing*, Vol 55 (12), pp 1771 - 1777.

Gruen, A. W., and Baltsavias E. P., 1987, "Geometrical Constrained Multiphoto Matching," *ISPRS Intercommission Conference on Fast Processing of Photogrammetric Data*, Interlaken, Switzerland, June, pp, 204 - 231.

Gruen, A. W., and Emmanuel P. B., 1986, "High Precision Image Matching for Digital Terrain Model Generation," *ISPRS*, Vol 26, Commission III, pp 284 - 296.

Gülch, E., 1996, "Fundamentals of Soft Photogrammetry Workstations," *Digital Photogrammetry*, American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland, pp 213 - 224.

Gülch, E., 1991, "Results of Test of Image Matching of ISPRS WG III/4," *ISPRS*, Vol 46, pp 1 - 18.

Hahn, M., 1992, "Towards Automatic DTM Verification Exploiting Stereo Orthophotos," *ISPRS International Archives of Photogrammetry and Remote Sensing*, Vol 28, Commission III, pp 233 - 240.

Hahn, M., 1989, "A System for Digital Stereo Image Matching," *Photogrammetric Engineering and Remote Sensing*, Vol 55 (12), pp 1765 - 1770.

Hassan, M. M., 1986, "A Special Analysis Method for Estimating the Sampling Density of Digital Elevation Models," *ISPRS International Archives of Photogrammetry and Remote Sensing*, Vol 26, Commission III, pp 306 - 316.

Hattori, S., Mori, C., and Uchida, O., 1986, "A Coarse-to-Fine Correlation Algorithm Considering Occlusions," *ISPRS International Archives of Photogrammetry and Remote Sensing*, Vol 26, Commission III, pp 317 - 328.

He, G. P., and Novak, K., 1992, "Automatic Analysis of Highway Features from Digital Stereo Images," *International Society of Photogrammetry and Remote Sensing*, Vol 28, Commission III, pp 119 - 124.

Heipke, C., 1992, "A Global Approach for Least Square Image Matching and Surface Reconstruction in Object Space," *Photogrammetric Engineering and Remote Sensing*, Vol 58 (3), pp 317 - 323.

HELAVA Associates Inc., 1986, "Socet Set System Administrators Manual," GDE Systems Inc., Telephone: 800-227-3104.

Helava, U. V., 1992a, "State of the Art in Digital Photogrammetric Workstations," ASPRS/ACSM/RT 92 Technical Papers, Washington, D. C., Vol 2, pp 10 - 18.

Helava, U. V., 1992b, "Prospects in *Digital Photogrammetry*" ASPRS/ACSM/RT 92 Technical Papers, Washington, D. C., Vol 2, pp 19 - 24.

Helava, U. V., 1988, "Object Space Least Square Correlation," Proceedings of 1988 ACSM-ASPRS Annual Convention, Vol 3, pp 46 - 55.

Helava, U. V., 1987, "Digital Comparator Correlation System," ISPRS Intercommission Conference on Fast Processing of Photogrammetric Data, Interlaken, Switzerland, June, 1987, pp, 404 - 417.

Helava, U. V., 1978, "Digital Correlation in Photogrammetric Instruments," *Photogrammetria*, Vol 34, pp 19 - 41.

Helava, U. V., 1977, "Digital Correlation in Photogrammetric Instruments," International Archives of Photogrammetry and Remote Sensing, Congress Helsinki, Commission II, Vol 21.

Helava, U. V., 1966, "A Fast Automatic Plotter," *Photogrammetric Engineering*, Vol 32 (1), pp 58 - 66.

Hellwich, O., Faig, W., 1992, "Graph Based Matching of Stereo Image Features," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 28, Commission III, pp 307 - 317.

Hoff, W., 1989, "Surface from Stereo: Integrating Feature Matching, Disparity, Estimation and Contour Detection," IEEE-PAMI Vol 11 (2), pp 121 - 136.

Jensen, J. R., 1996, "Issues Involving the Creation of Digital Elevation Models and Terrain Corrected Orthoimagery Using Soft-copy Photogrammetry," *Digital Photogrammetry*, American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland, pp 167 - 179.

Jeyapalan, K., 1992, "Photogrammetry", In Encyclopedia of the Earth System Science, Vol 3, Academic Press Inc.

Jeyapalan, K., Stein, M. A., Awuch-Buffour, R., Wang, J., Luzen, B., and Wang Y., 1992, "Use of GPS for Photogrammetry," Iowa State University, Ames.

Kaiser, B., Schmolla, M., and Wrobel, B. P., 1992, "Application of Image Pyramid for Surface Reconstruction with FAST Vision (=Facets Stereo Vision)," *ISPRS International Archives of Photogrammetry and Remote Sensing*, Vol 28, Commission III, pp 342 - 374.

Kölbl, O., Bach, U., Gasior, D., and de laporte, K., 1992, "Multi-Templet-Matching for the Automation of Photogrammetric Measurements," *ISPRS International Archives of Photogrammetry and Remote Sensing*, Vol 28, Commission III, pp 540 - 548.

Kölbl, O., 1991, "The DSR 15T - A System for Automatic Image Correlation," 1991 ACSM-ASPRS Annual Convention, Vol 15, pp 218 - 227.

Kölbl, O., 1990, "Automatic Derivation of A DTM," ACSM-ASPRS Annual Convention, Vol 5, pp 54 - 66.

Kölbl, O., 1989, "Replacement of Human Operator By Image Processing Shown on the Example of Elaboration of A DTM," 1989 CSM-ASPRS Annual Convention, Vol 2, pp 126 - 141.

Kölbl, O., Boutaleb, A. K., and Penis, C., 1987, "A Concept for Automatic Derivation of A Digital Terrain Model with the KERN DSR11," *ISPRS Intercommission Conference on Fast Processing of Photogrammetric Data*, Interlaken, Switzerland, June, pp, 306 - 317.

Krupnik, A., and Schenk, T. 1992, "Segmentation of Edges in 3-D Object Space," *ISPRS International Archives of Photogrammetry and Remote Sensing*, Vol 28, Commission III, pp 522 - 527.

Krzystek, P., and Ackermann, F., 1995, New Investigation into Practical Performance of Automatic DEM Generation," ACSM/ASPRS Annual Convention & Exposition Technical Papers, Vol 2, pp 488 - 500.

Li, M. X., 1990, "High Precision Relative Orientation Using Feature-based Matching Techniques," *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol 44, pp 311 - 324.

Lin, Z. J., 1986, "Multi-Criterions for Similarity Assessment in Photogrammetric Image Correlation," *ISPRS International Archives of Photogrammetry and Remote Sensing*, Vol 26, Commission III, pp 415 - 426.

Lo, K. C., and Mulder, N. J., 1992, "High Precision DEM Generation from SPOT Stereo Imagery by Object Space Least Square Matching," *International Archives of Photogrammetry and Remote Sensing*, Vol 28, Commission III, pp 133 - 137.

Luhman, T., and Altrogge, G., 1986, "Interest-Operator for Image Matching," *International Archives of Photogrammetry and Remote Sensing*, Vol 26, Commission III, pp 459 - 474.

Makarovik, B., 1992, "Consideration on Image Matching - An Engineering Perspective," *ISPRS Vol 29 (2)*, pp 613 - 622.

Masry, S. E., 1974, "Digital Correlation Principles," *Photogrammetric Engineering*, Vol 40 (3), pp 303 - 308.

Maune, D., 1996, "Introduction to Digital Elevation Model (DEM)," *Digital Photogrammetry*, American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland, pp 131 -134.

Miller, S. B., 1992a, "Automatic Elevation Extraction and the Digital Photogrammetric Workstation," ASPRS-ACSM Annual Convention, pp 572 - 580.

Miller, S. B., 1992b, "Softcopy Photogrammetric Workstations," *Photogrammetric Engineering and Remote Sensing*, Vol 58, 1, pp 77 - 83.

Nelson, M, 1993, "VR can be as Important as the Development of the Mouse", Next Generation VR Conference, Sarnoff, June.

Pertl, A., 1985, "Digital Image Correlation with An Analytical Plotter," *Photogrammetria*, 40, pp 9 - 19.

Piechel, J., 1986, "Investigations on Different Interest Operators for DTM-Generation by Epipolar Line Correlation," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 26, Commission III, pp 564 - 572.

Qiu, Z. C., and Liu, Y. T., 1992, "A Research of Boundary Extraction Based on Zero Crossing of Second Directional Derivatives," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 28, Commission III, pp 43 - 46.

Rauhala, U. A., 1992, "Automation of Global Digital Image Matching by Array Algebra," ASPRS/ACSM/RT Technical Papers, Washington, D. C., Vol 2, pp 65 - 75.

Rauhala, U. A., 1987, "Fast Compiler Positioning Algorithms and Techniques of Array Algebra in Analytical and *Digital Photogrammetry*, ISPRS Intercommission Conference on Fast Processing of Photogrammetric Data, Interlaken, Switzerland, June, pp, 156 - 178.

Reis, M. L., 1992, "Optimized algorithm for Three Dimensional Image Reconstruction," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 28, Commission III, pp 335 - 340.

Rosenholm, D., 1987, "Least Square Matching Method: Some Experimental Results," *Photogrammetric Records*, 12 (70), pp 493 - 512.

Rosenholm, D., 1987, "Empirical Investigation of Optimal Window Size Using Least Square Image Matching Method," *Photogrammetria*, (PRS), Vol 42, pp 113 - 125.

Rosenholm, D., 1987, "Multi-point Matching the Least Squares Technique for Evaluation of Three-Dimensional Model," *Photogrammetric Engineering and Remote Sensing*, Vol 27, pp 621 - 626.

Rosenholm, D., 1986, "Accuracy Improvement of Digital Matching for Evaluation of Digital Terrain Model," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 26, Commission III, pp 573 - 587.

Russel, R. L., McClain, R. A., Landell, B. and Patrick, 1992, "A 3-D Model Extraction System," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 28, Commission III, pp 446 - 451.

Saleh, R. A., and Scarpace, F. L., 1992, "Multispectral Matching Technique for DTM Generation," ASPRS/ACSM/RT Technical Papers, Washington, D. C., Vol 2, pp 36 - 46.

Scarano, F. A., 1976, "A Digital Elevation Data Collection System," *Photogrammetric Engineering and Remote Sensing*, Vol 42, (4), pp 489 - 496.

Schenk, A., 1986, "Stereo Matching Using Line Segments of Zero Crossing," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 26, Commission III, pp 602 - 607.

Schenk, T., and Toth, C. K., 1992, "Reconstructing Small Surface from Multiple Images," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 28, Commission III, pp 255 - 258.

Schewe, H., and Förstner, 1986, "The program PALM for Automatic Line and Surface Measurement Using Image Matching Techniques," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 26, Commission III, pp 608 - 622.

Schewe H., and Förstner, 1986, "A Feature Based Correspondence Algorithm for Image Matching," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 26, Commission III, pp 150 - 163.

Smith, G., 1995, "Digital Orthophotography and GIS," ESRI User Conference, Redlands, CA.

Stefanidis, A., and Schenk, T., 1992, "On Application of Space Scale Techniques in *Digital Photogrammetry*," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 28, Commission III, pp 586 - 590.

Strange, W. E., Vincent, S. F., Berry, R. H., and Marsh, J. G., 1972, "Detailed Gravimetric Geoid for the United States," *The Use of Artificial Satellite for Geodesy, Geophysical Monograph*, 15. Eds. S. W. Henriksen, A. Mancini, B. H. Chovitz, Washington: American Geophysical Union, pp 169 - 172.

Tetley, L., and Calcutt, D., 1986, "Electronic Aids to Navigation," London, Edward Arnold Ltd., pp 225 - 232.

TNTMips5.6, 1997, Online Reference Manual, Microimages Inc., Lincoln, Nebraska.

Vision International, a division of Autometric Inc., 1996, "SoftPlotter Product Functional Description, Version 1.6," 502 Earth City Expressway, Suite 203, Earth City, MO 63045. Telephone: 314-770-2015.

Wrobel, B. P., 1991, "Least-square Method for Surface Reconstruction from Images," *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol 46, pp 67 - 84.

Wrobel, B. P., 1987, "Fast Stereo vision (FAST vision) - A New Approach to Computer Stereo Vision and to *Digital Photogrammetry*," Proceedings of Intercommission Conference on Fast Processing of Photogrammetric Data, Interlaken, Switzerland, June, pp, 231 - 258.

Zhang, J. Q., Zhang, Z. X., and Wang, Z. H., 1992, " High Accurate Location on Digital Image and Application in Automatic Relative Orientation," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 28, Commission III, pp 78 - 82.

Zhang, Y. N., 1992, "A New Stereo Matching Approach in Image/Object Dual Space," ISPRS International Archives of Photogrammetry and Remote Sensing, Vol 28, Commission III, pp 534 - 539.

Appendix A

Hardware

Description of Hardware

1. SiliconGraphic Indigo2™ and XL/XL Dual Head Graphics

The hardware inventory from the system is listed as:

Iris Audio Processor: version A2 revision 1.1.0
1-200 MHz IP22 Processor
FPU: MIPS R4010 Floating Point Chip Revision: 0.0
CPU: MIPS R4400 Processor Chip Revision: 6.0
On-board serial ports: 2
On-board bi-directional parallel port
Data cache size: 16 Kbytes
Instruction cache size: 16 Kbytes
Secondary unified instruction/data cache size: 2 Mbytes
Main memory size: 64 Mbytes
EISA bus: adapter 0
Integral Ethernet: ec0, version 1
Integral SCSI controller 1: Version WD33C93B, revision D
Disk drive: unit 5 on SCSI controller 1
Tape drive: unit 2 on SCSI controller 1: DAT
Integral SCSI controller 0: Version WD33C93B, revision D
CDROM: unit 3 on SCSI controller 0
Disk drive: unit 1 on SCSI controller 0
Graphics board: XL
Graphics board: XL

Basically this is a system with 200 MHz processor with FPU, 64 MB memory. Two disk drives(2GB internal and 4GB external), one tape drive(4mm DAT), one CDROM are used as input/output devices. Dual head display is used.

2. Use of Storage Space

Take the high94 project as an example. There are three photographs in this project. The total storage space used by the three digital images is about 60 MB, at a resolution about 50 μ . The use of the whole project is:

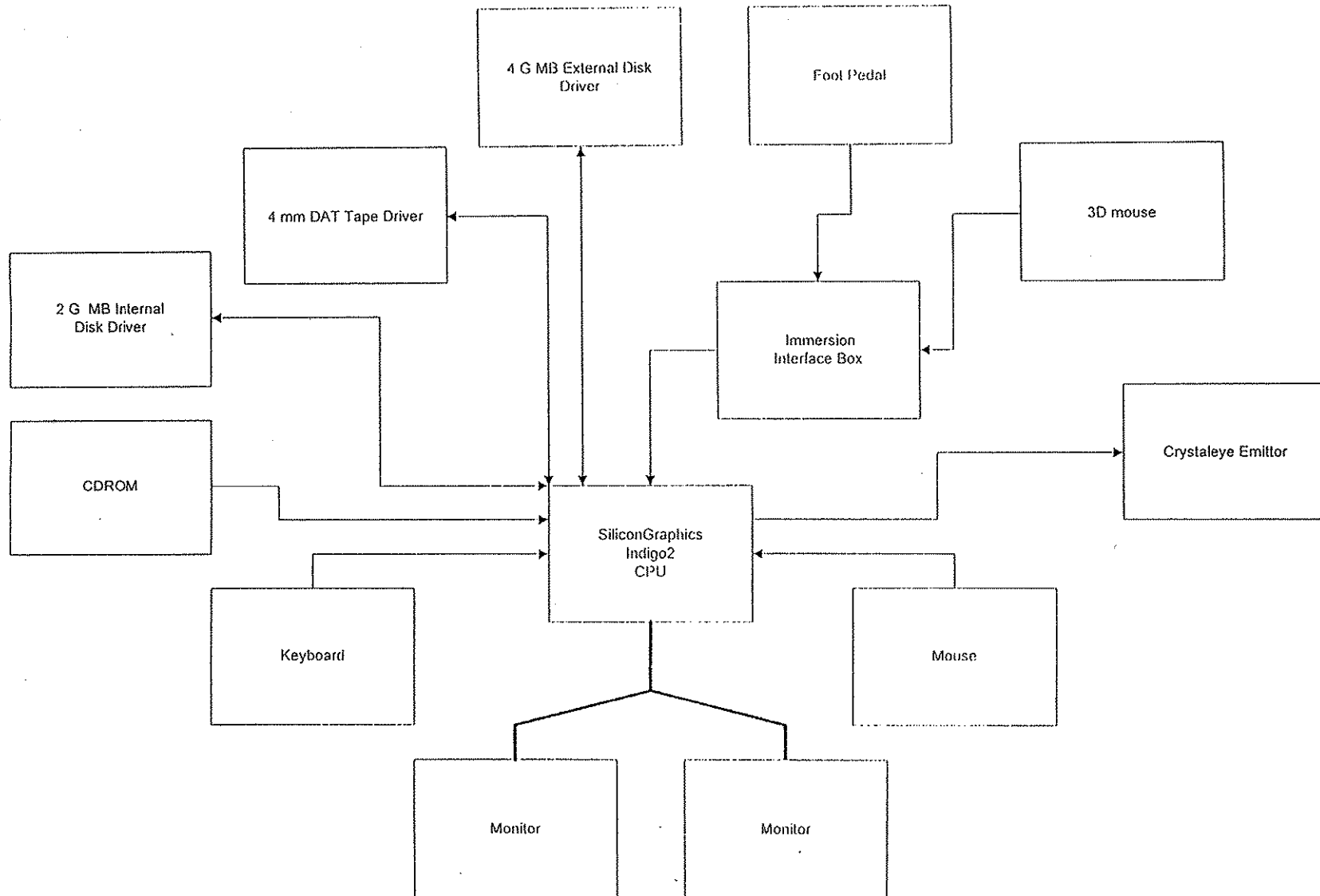
- Block Tool: 43 MB
- Stereo Tool: 61 MB
- DEM Tool: 0.6 MB
- Surface Tool: 22 MB
- Ortho Tool : 2 MB
- KDMS Tool: 2 MB

The sum of the above is about 200 MB, including the raw images. The space used in DEM Tool, Surface Tool depends on the ground spacing and the size of area of interest. Here a ground space of about 10 meters was used.

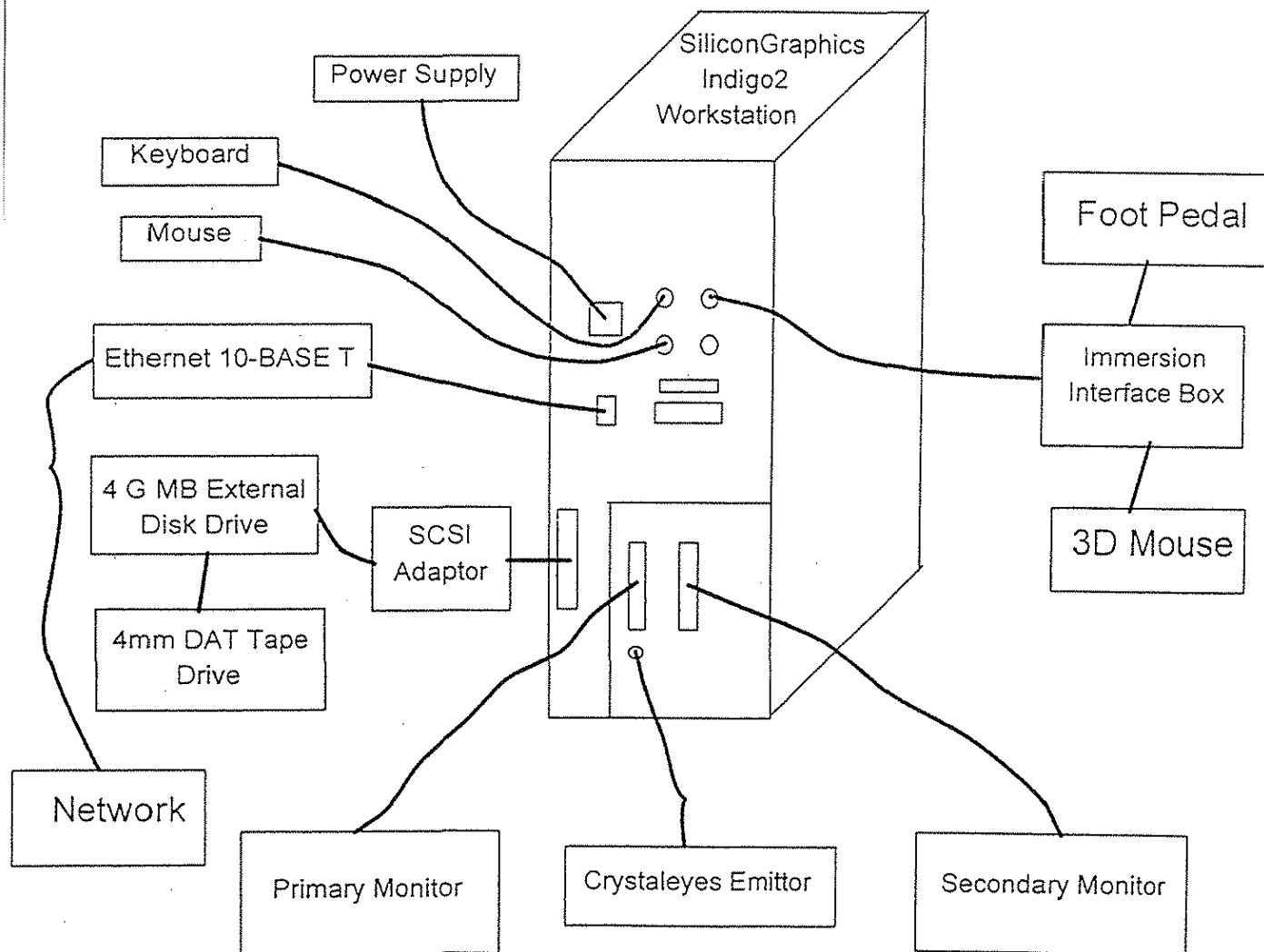
3. 3D Mouse, Foot Pedal and Crystaleye Stereo Viewing

3D mouse, foot pedal is used to facilitate the control and digitizing process. The Crystaleye stereo emitter is used to control the displaying of the stereo images for stereoviewing. Their connection to the system is shown in the hardware connection diagrams.

Hardware Schematic Diagram

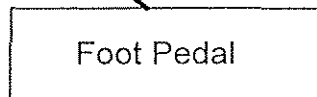
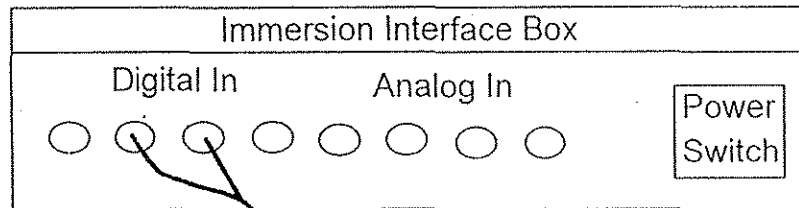


Hardware Schematic Diagram

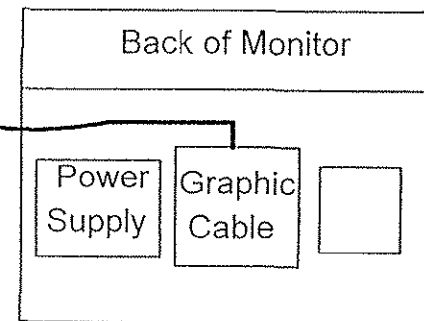
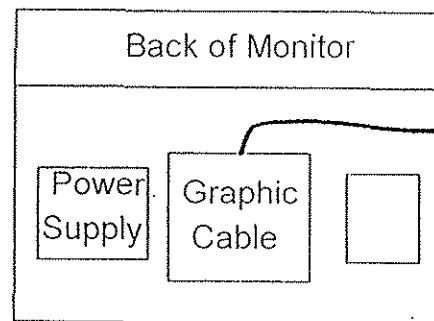
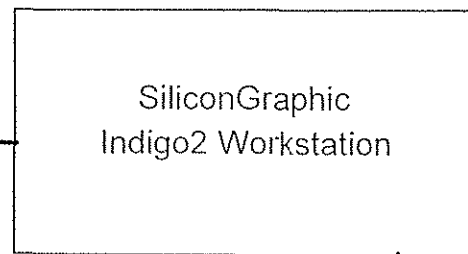
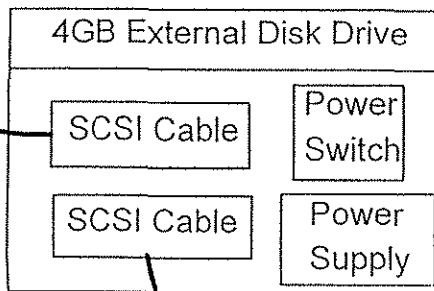
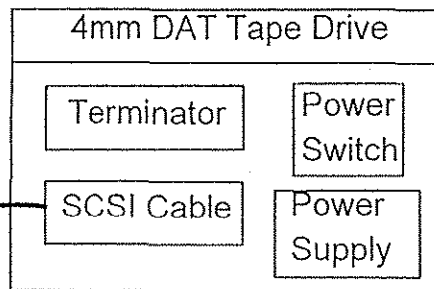
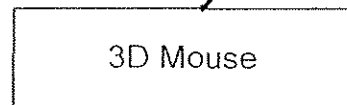
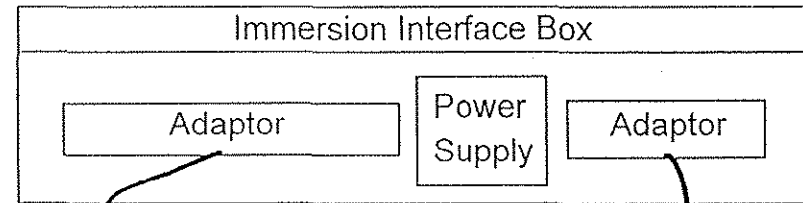


Hardware Connections

Front of the Immersion Interface Box



Back of the Immersion Interface Box



Appendix B

Software

Description of Software

1. System

The system is based on UNIX system, here IRIS from SiliconGraphics is used as the software environment. All the commands like cp, ls, rm, mkdir, rmdir and so on can be performed. To start SoftPlotter, type

% softplotter

Here % is the system prompt.

2. SoftPlotter

SoftPlotter is a menu-driven software, it consists of two major parts: Tool Bar and the individual modules. All the individual modules are arranged inside the Tool Bar.

Tool Bar

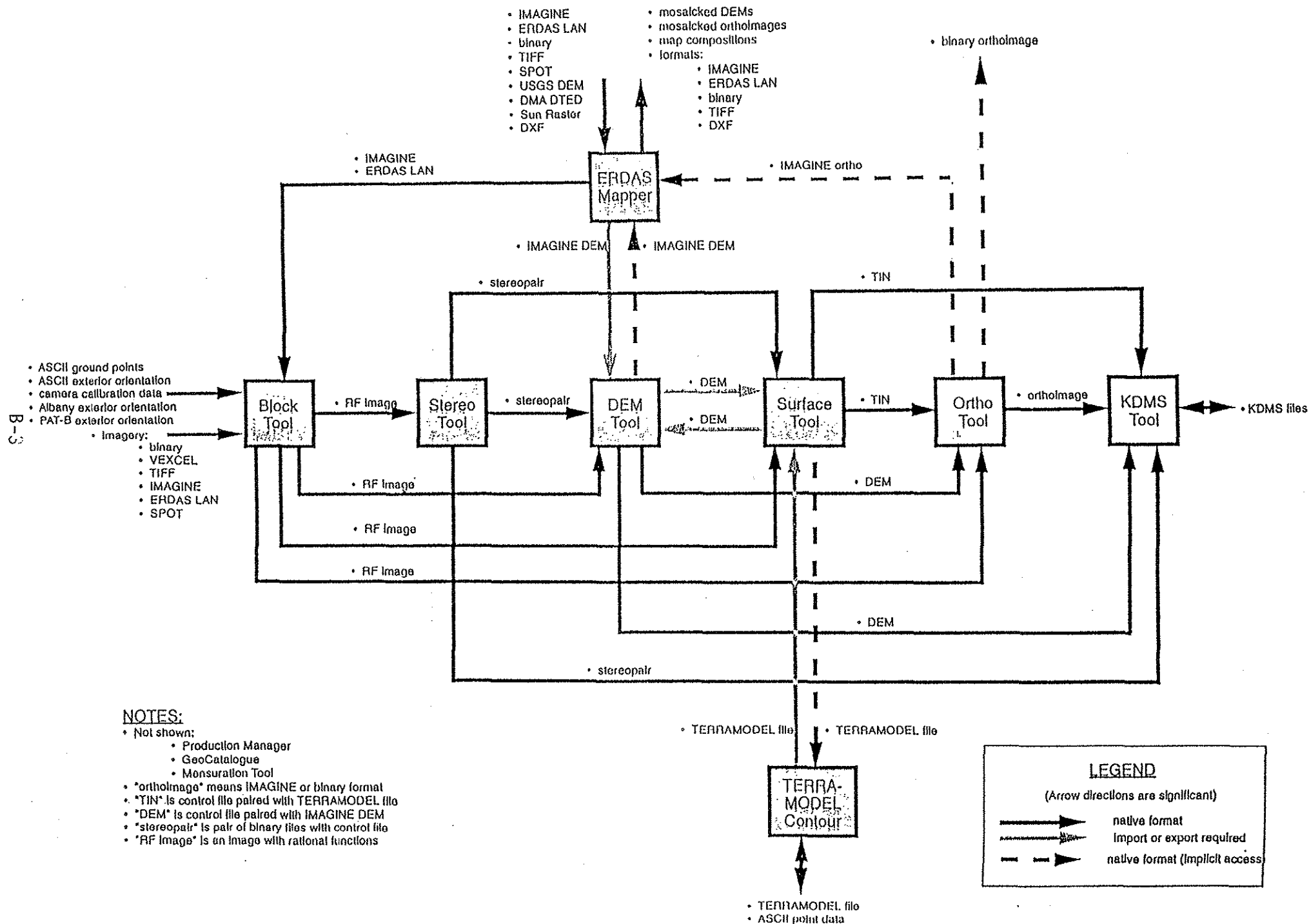
The Tool Bar contains the database and definitions for the whole project, it also controls the invocation of all these individual modules or tools. Under the Tool Bar the following functions can be done:

- New project Directory: create a new project directory
- Set Project Directory: change from the current project directory to another project directory
- About SoftPlotter: *Something about SoftPlotter*
- Exit: exit from SoftPlotter
- Project Definition: change the definition of the current project such as the reference frame, the type of projection, format of the outputs and so on.
- Camera Editor: edit or add new camera interior orientation data in the central camera database so that it can be used in any of the projects.
- Projection Editor: edit the projection or add a new project to the projection database
- Coordinate Calculator: convert the coordinates from one reference frame to another
- Set Preference: set the preference used in this project
- Use Current Project As Default: set the current project as default project

The individual modules contained in the Tool Bar are:

- PM Tool
- Block Tool
- Stereo Tool
- DEM Tool
- Surface Tool
- Ortho Tool
- Mosaic Tool
- Measurement Tool
- KDMS Tool
- DGN Tool
- IMAGINE
- TERRAMODEL

Individual Modules

B
I
G

Appendix C

Comparison of Softwares

A Report On

INTEGRAPH INTEGRATED
NT-DIGITAL PHOTOGRAM-
METRY SYSTEM

vis-a-vis

SOFTPLOTTER

By
Dwipen Bhagawati

Submitted to
Prof K Jeyapalan

1.0 DIGITAL PHOTOGRAMMETRIC WORKSTATION

A digital photogrammetric workstation (DPW) is different from an analytical plotter in terms of the input data as well as the potential for automated image measurement and matching. The input data in case of a DPW is a scanned image that is of very large size, for example, about 133 megabytes for an aerial photograph of size 230 x 230 millimeter scanned at 20 micrometer resolution. Such large sizes are handled through smart file formats and image compression techniques in some softwares. Smart file formats is capable of efficient memory management and efficient processing through use of such techniques as image tiling and image pyramids. The digital technology adds the new valuable techniques of automated image measurements and image matching. In this report, a comparative discussion of two digital photogrammetric systems, viz., **Integraph Integrated NT digital system** and **SoftPlotter softcopy workstation** is attempted.

1.1 Integraph Integrated NT Digital System

This system is a product from the INTEGRAPH Software Solutions. The system architecture includes

- **Symmetric Multiprocessing (SMP)** architecture that allows system scalability
- **Windows NT** operating system that offers scalability across generations of processors, support on multiple processor families and a native implementation of symmetric multiprocessing
- **Open Graphics Library (OpenGL)** for faster raster and vector operations which is an open Application Programmer's Interface for high performance, technical graphics operations with native support for stereo display.

The capabilities of **ImageStation** products supports such requirements as

- Management of very large images
- Support for very large monitors
- Smooth and continuous roam across the entire image
- Stereo display in a window
- Stereo vector superimposition
- Fully functional data capture during roam
- 16 bit per pixel panchromatic stereo processing
- Epipolar resampling
- Bicubic interpolation
- 5 x 5 convolution filtering

- Automatic convolution filter selection during zoom
- Automatic dynamic range adjustment
- N bit to 8 bit display mapping and gamma correction

The on-the-fly epipolar resampling is supposed to remove time consuming step of batch resampling images prior to stereo exploitation. The other requirements were to enhance greatly quality of displayed imagery so that the task of image enhancement is no more necessary.

It is possible to use advanced processor technology as they are available in the future with minimum of system modifications.

1.2 SoftPlotter™ Softcopy Workstation

SoftPlotter is an object oriented design and is based on **Silicon Graphics, Inc. (SGI)** hardware. **SGI** is capable of performing all phases of photogrammetric production process. The object oriented design aspect of the **SoftPlotter** product allows the system to be extended to meet unique customer requirements. It also uses an open system computer technology.

The miscellaneous software capabilities include

- Flexible use of reference frames (geographic, map projections, arbitrary cartesian, terrestrial (terrestrial only)); products can be generated in any reference frame regardless of the source data reference frames
- Switching of linear units for any product at any time
- Use of **Reduced Resolution Data Sets (RRDS)** to speed up image data access at other than 1:1 processing and all display functions; these are in files independent of the source image and can be deleted to free up disk space since they can be generated as and when required.
- Batch processing capability that allows the user to generate script file for sequential processing (e.g., stereopair creation, DTM generation, orthorectification)
- Use of "project definition parameters" to provide default parameters for most processing steps; for example, DTM collection spacing, orthophoto resolution, linear units and reference frame, so that data entry is minimized.
- The SoftPlotter product comes standard with **ERDAS IMAGINE** software, **Plus 3 Teramodel** Contour software, and -optionally, with **MicroStation** from Bentley Systems.

2.0 HARDWARE CONFIGURATIONS

2.1 Integraph Integrated NT Digital System

The **Integraph integrated digital photogrammetric system** consists of the following hardware components:

- Photoscan TD
- ScanServer
- Imagestation Z

PhotoScan TD is a manually operated system that includes the scanner module with or without the roll-feed capability and a host workstation running under the Windows NT operating system. The base system includes 4 GB of disk storage and will accommodate additional internal or external disk drives. Scanning may be performed at resolutions of 7, 14, 21, 28, 56, 112 and 224 microns. The tricolor CCD is capable of single pass color scanning.

ScanServer is an alternative to **PhotoScan TD**. It is a system for automatic scanning of roll feed based film. This system includes a scanner module as in PhotoScan TD but with roll feed option and a server class workstation with a **RAID** disk subsystem. It has a 27 GB disk capacity, hardware **JPEG compression**, tape backup system, and a complete display system including a 21" monitor. The base system can accommodate up to five additional 9 GB disk drives. More disk expansion can be added through addition of a second InterRAID cabinet. It has the capability of acting as an image server for a small cluster of processing workstations. The **AutoScan Software** helps unattended scanning of roll film. Some main features of AutoScan Software are:

- Scan Project Management
- Automatic film positioning
- Automatic radiometric measurements
- Automatic fiducial measurement
- Automatic image pyramid generation
- File name, disk space management
- Network Scanning
- Project Report

ImageStation Z offers stereo roam capability that allows moving the stereomodel smoothly behind the measuring mark, similar to moving the stage or plates behind the floating mark on analogue or analytical stereoplotters. This enables the operator to follow features such as rivers and roads across the extent of the stereo model. The other main features of the ImageStation Z are;

- Stereo viewing kit; ten-button two-handed cursor

- High precision D-sized (34" X 22") digitizing surface in a single surface table ; Adjustable Cyborg Chair
- JPEG image Compression Processor
- Expandable deskside chassis with dual or quad 200Mhz Pentium Pro CPU or 512KB cache per CPU
- 128 MB of memory (4 banks/8 SIMM sockets total)
- Single or dual RealizM Z25 3D graphics accelerator providing a maximum resolution of 2.5Mpixels
- Single 21", dual 21" or single 28" multi-sync high resolution monitor; Single surface monitor table
- One 4GB system drive and two additional 4 GB internal disk drives
- Separate internal (fast 20) and external SCSI buses; 8X CD-ROM
- Ethernet controller with 10/100Base-TX support
- Creative Labs Sound Blaster -16C™ audio with FM synthesizer
- One parallel port and two 16C550 compatible serial ports
- Three front accessible 5.25" drive bays available; the front accessible bays also support internal 3.5", 1" disk drives
- Multimedia keyboard, 3-button mouse, 3.5" floppy disk drive
- One copy of Windows NT operating system

2.2 SoftPlotter™ Softcopy Workstation

SoftPlotter uses the fast 200MHz SGI Indigo² workstation based on UNIX that has a 4 MB secondary cache. Peripherals includes

- 8mm Exabyte and 9-track tape drive
- A CD-ROM drive
- A 20GB external disk drive

Stereographics field sequential display image technology is used for stereoviewing. The system features an interactive 3D cursor known as **SoftMouse**. It is a custom designed and ergonomically shaped photogrammetry measuring device.

3.0 SOFTWARE CONFIGURATION

3.1. Integrgraph Integrated NT Digital System

The workflow in Integrated NT-Digital Photogrammetry System may be grouped into two categories:

1. **Visual Database Creation** that includes photo scanning, image mensuration and triangulation (orientation and/or bundle block adjustment), and epipolar image generation, if necessary. The epipolar imagery may be generated on the fly.
2. **Visual Database Exploitation** that includes 3-D feature /DTM collection, CAD model generation, and orthophoto creation.

3.1.1. Digital Mensuration And Triangulation

ImageStation Photogrammetric Manager (ISPM) provides photogrammetric data management tools with entry/edit menus, the bulk input/output of photogrammetric data and import/export options for third party photogrammetric packages.

Orientation And/Or Triangulation:

ImageStation Model Setup (ISMP) is a module for single image/model orientation and provides functionalities for Interior Orientation, Relative Orientation, Absolute Orientation and single image resection.

ImageStation Digital Mensuration (ISDM) provides a multi-image (up to six images at a time), multi-sensor point transfer and measurement environment for photo triangulation workflow. Facility for Auto Correlation and on-line integrity checks are provided for better accuracy. It is possible to access Image enhancement and image manipulation functions while performing the mensuration task.

Conventional Bundle Block Adjustment

PhotoT, which is included in **ISDM** product provides the user with an interactive interface to perform conventional bundle adjustment process. Standard least square bundle adjustment procedure is used incorporating apriori information for exterior orientation parameters. In addition, such operations as blunder detection, variance-covariance computation, detecting photos/models, quality control analysis for IO, RO, AO, Bundle adjustment parameters, drawing footprints, drawing 3-D points, and bulk processing can be performed in **PhotoT**.

Automatic Bundle Block Adjustment

ImageStation MATCH-AT (ISAT) is an automated aerotriangulation package combined with editing facility and provides an interface with **ISDM**. The main module here, **MATCH-AT** automates point transfer and tie point measurements. However, an initial parameter set-up, the interior orientation, and interactive measurement of control points are required at the beginning. The results of automatic block adjustments can be analyzed and edited if necessary. As good approximate values of the exterior orientation parameters are critical for successful image matching, it is suggested such values be obtained from onboard Global Positioning System (GPS) or Inertial Navigation System (INS). **MATCH-AT** uses image pyramids and coarse to fine resolution image matching operations in order to overcome some of the difficulties, including uncertainty due to terrain relief, regarding initial approximation of parameters.

3.1.2. Epipolar Resampling

Epipolar resampling involves rearrangements of pixels in each digital photo of a stereomodel in such a way as to remove all the y-parallaxes. The result is the removal of effects of tilt, dip and swing of the aircraft and such other corrections as earth curvature, atmospheric refraction, lens distortion. However, it is not necessary to create stereo epipolar imagery in advance for 3-D exploitation using Integrgraph NT based photogrammetry products.

3.1.3 3-D Feature And DTM Extraction

After triangulation and orientation is completed, resampling into epipolar geometry is done on the fly for each stereo model. 3D feature/DTM extraction is carried out by ImageStation Stereo Display (ISSD), MicroStation Feature Collection (MSFC), ImageStation DTM Collection (ISDC) and ImageStation MATCH-T (ISMT) products.

Stereo Display

ImageStation Stereo Display (ISSD) displays and manipulate monochromatic, color index and color composite images and uses layer capability to load and process multiple image file. It uses image interlace technology for stereo display.

Map Feature Collection

MicroStation Feature Collection (MSFC) provides a digitizing system for collecting and editing map features and uses screen-based icon-driven menus to provide an interface designed for map production.

DTM Collection

ImageStation DTM Collection (ISDC) provides an interactive method for stereo compilation of digital terrain model using MSFC to setup feature definitions such as DTM points and breaklines for ISDC. The collected elevation data can be used by Integrgraph DTM products such as MSM, InRoads or InSurv to create contours or other engineering modeling. It can also be used in MGE product to creation and revision of digital land base.

Automatic DTM Collection

ImageStation MATCH-T (ISMT) provides a method for automatic generation of elevation data via batch processing. DTM points are extracted from digital aerial and SPOT stereo pair images in a stepwise manner by going through a pyramidal data structure. At each pyramidal level, a preliminary matching of conjugate image points are made, projected into an object space for 3-D intersection and processed through a robust DTM modelling with bilinear finite elements. The main features of ISMT are:

- Raster file structure
- DTM generation in a model, object or user defined coordinate system
- DTM generation from B&W and color imagery
- SPOT image capture using Rational Functions
- Batch Processing and output into design file
- Suppression of grid points near breaklines
- Separate class definition and symbologies for points of different statistical qualities
- Use of exiting DTM points to improve automatic DTM generation
- Use of surface reconstruction module to capture DTM points in poor texture areas
- On-line visualization tools to monitor DTM point quality
- Borderlines that are exploded to avoid edge effects

3.1.4 Orthophoto Generation

Base Rectifier is a component of the ortho rectification system. It can create a digital orthophoto from an input image. Any ground feature collected in stereo 3-D extraction can be displayed in their true orthographic positions directly on top of the newly generated orthophoto. Additional digitizing in 2-D can also be performed directly on top of the orthophoto. The output pixel size can be chosen in terms of ground units or by defining the number of rows and columns in the output image. The user can define the type of resampling method, the pixel spacing for the anchor points, different tile sizes, the number of overviews and how they are processed, and the coordinates and rotation of the output image. Integrgraph DTM products can be used to analyze plan or perspective view of topographic features, triangles, surface mesh, contours, and color-coded

elevations. Design files can be created in the required projection system. **IRASC** or **MBI** products can display orthophotos, do mosaicking, digitize, and annotate required planimetric features.

3.2 SoftPlotter™ Softcopy Workstation

A **Graphical User Interface (GUI)** based on OSF MOTIF is used throughout the SoftPlotter system features **Production Manager** tool that allows point and click archiving and dearchiving of project at any level from a single file to a full back up provide automatic data organization for the user. Thus the UNIX operating system and commands are sheltered from the user to a great extent. I.e., the SoftPlotter is built around a "Project" concept. A project contains source data, interim products, and final products. The **Tool Bar** serves as the launching pad for the various modules of the SoftPlotter software .

3.2.1 Import

SoftPlotter accepts scanned images, color or black and white from all major scanners. Standard imagery import features are included for ERDAS IMAGINE, ERDAS LAN, TIFF. Vexcel scanner, Wherli scanner, and generic binary file formats. It also imports SPOT imagery in the 1A and 1B formats, both multispectral and panchromatic.

3.2.2 Triangulation

Triangulation data can be imported in standard ASCII output file from external packages **PAT-B**, **JFK**, and **ALBANY** software packages, or may be performed on the system. SoftPlotter uses **Multi Sensor Triangulation (MST)** which supports simultaneous triangulation of standard frame, terrestrial, aerial, satellite and panoramic imagery. The bundle adjustment is based on rigorous sensor models and computes rational functions for each image after the bundle is complete. The rational function is utilized in all subsequent operations making the software sensor-independent.

The SoftPlotter triangulation carries out a least square block bundle adjustment with precision assigned to all parameters in the solution measured and known. Individual image measurements of ground points and images can be individually turned on or off. The **Block Tool** module is responsible for import of imagery, interior orientation of all imagery, the triangulation process, and creation of support data for all frames in the triangulation.

The **Stereo Tool** generates stereopairs for general viewing. The stereopairs are formed by epipolar resampling of the imagery to create a parallax-free set of images. The stereopair so created are sensor independent. A floating cursor is implemented. The epipolar cursor is controlled by the **SoftMouse**.

3.2.3 Batch Processing and Automation

SoftPlotter has a batch scripting process to allow computation intensive tasks by lining up stereopairs, DTM collections and orthophotos in advance to run during off hours when interactive processing such as triangulation measurements, interactive editing of DTM and mosaicking is not being performed. The applicable processes include:

- Automatic Interior Orientation (AIO) of digitized imagery and import of the imageries into designated blocks.
- Automatic Tie Point Selection and Measurements (ATPS) on entire strips. Only ground point identification and measurement is to be done by the operator.
- Stereopair warping.
- Automatic DTM Collection.
- Orthophoto generation.

3.2.4 DTM / TIN

The **DEM Tool** is used to automatically collect DEM from overlapping images by a proprietary digital correlation technique. It provides interactive stereoscopic editing, import of external DEMs (ERDAS IMAGINE format), and exporting DEM data to a binary format.

The **Surface Tool** is commonly used to describe terrain surface and is based on TIN data storage formats. It is different from the DEM Tool in that it collects data relative to the stereomodel boundary as opposed to a "North Up" orientation in ground space. It generates contours in near real time with variable interval and displays with color coding. It also can interact with the **KDMS Tool**, if present, to provide professional contouring and additional terrain data editing functions.

Existing 2D files, commonly in vector format, may be imported into SoftPlotter and view with stereo superimposition by passing the horizontal coordinates through the TIN surface to determine elevations for all points. The **Plus 3 TERRAMODEL Contour Package** provided with the system offers additional capabilities in TIN manipulation, contouring and profiling, including import and export of ASCII and DXF file data.

3.2.5 Vector Mapping / Data Capture

The **KDMS Tool** (Kork Digital Mapping System) and the **DGN Tool** are vector mapping softwares for map compilation, built upon the **SoftPlotter Application Programmer Interface (API)**. The files are in standard KDMS file format and Standard DGN file format respectively.

3.2.6 Orthophoto Generation / Mosaicking

The **Ortho Tool** handles orthorectification of images from the triangulation based on DEM or TIN terrain information through batch processing. It is used to generate digital orthoimages for the mosaicking step. The **Mosaic Tool** does the job of mosaicking the orthoimages into a single image file. The tool includes the ability to simply collage an area or the use of interactive cutlines and feathering for seamless image generation.

3.2.7 Image Processing

SoftPlotter is fully integrated with **ERDAS IMAGINE** Mapper. SoftPlotter uses **IMAGINE Tool** for raster and vector data import, image processing, map composition and plotting. It works in native ERDAS file formats for imagery and DEMs.

4.0 CONCLUSION

It can be seen that the INTEGRAPH system has added hardware units for scanning of photo data whereas the SoftPlotter depends upon already scanned data for subsequent treatments.

In regard of basic computational photogrammetric functionalities, the INTEGRAPH uses third party products such as MACH-AT, whereas the SoftPlotter, though seems to be self sufficient in this regard, provides optional use of products such as Plus 3 TERRAMODEL.

For other photogrammetric purposes such as mapping and digitizing, both the systems integrate with themselves already existing and products of proven capabilities.

Both these systems seem to be comparable in matters of photogrammetric products generated. Yet different tools used for various steps of processing of photogrammetric data is different.

Comparison between SoftPlotter and Socet

By

W.Yao

Comparison between **SoftPlotter** and **Socet**

SoftPlotter is a digital photogrammetry software package from **Vision International**, and **Socet** is a digital photogrammetry software package from **Heleva Inc.** Both software can be used to perform what can be done in the conventional photogrammetry.

The general advantage of **SoftPlotter** is that everything in it is well grouped into some modules so that it is easy to know how to do the processing according to the module tools and to manage the information in it. Since all the functions in **Socet** are grouped by different levels of menus in terms of the similarity or processing procedures, it is not so easy to learn how to use it. But **Socet** has more complicated and complete functions that can deal with more situations than **SoftPlotter** does. From the view of capability, **Socet** is more professional.

1. Appearance & User Interface

They have totally different appearance on the screen. **SoftPlotter** has a tool bar which shows all the function modules available on it. All the modules are arranged in the order of processing, so the user is easy to know what is the next step. So the operator can use it even without referring to manual or with a little help.

In **Socet** there is no such module menu like in **SoftPlotter**. Basically it consist of three separate windows. The upper one has all the functions in the menu, the middle one is for displaying images, the lower one controls the image displaying in the middle window. For stereo displaying, there is another window on the second monitor for displaying images. since all the function in the upper window are not grouped into the function modules like in **SoftPlotter**, it is not easy for users to learn how to use them.

The general impression is that the **Socet** is much more complicated than **SoftPlotter**, whether the functions or the operations. Since **SoftPlotter** has its all functions in modules, and put them on the tool bar in the order of processing, it is more efficient than

the **Socet** has. It is not difficult to add more complicated functions to **SoftPlotter** to improve its processing precision or functionality for each module if needed.

Table 1 lists some comparison between them for the function of the main menu.

Table 1 Main Menu Comparison

	SoftPlotter	Socet
Function in Modules ?	Yes	No
Users friendly ?	Yes	Not much
Image Window always available ?	No, different image window for different function	Yes, always the same image window
Save current status when exit?	No, it uses default project	Yes, it will come back to the same status next time
Main menu complicated ?	No, there is only one tool bar	Yes, Three separate window menus can be messed up

2. Create New Project

Both software have the creation new project as the first step in a new project. In **SoftPlotter** the information like project name, projection or datum, average height, output image format and ground spacing of DTM are needed. Once a new project is created, a subdirectory under the project name is created and a certain number of subdirectory under that project subdirectory are made for storing the input and output of corresponding module. Unlike **SoftPlotter**, in **Socet** the path for images and project file is needed for the new project. all the input and output will be put in these two subdirectories. If not using the default path, the subdirectory for the new project needs to be created before setting the path in the definition of the new project. Coordinate system and estimate of the minimum and maximum ground elevations are needed. Table 2 shows the comparison on creating new project.

Table 2 Creating New Project

	SoftPlotter	Socet
Subdirectory for each	Yes. This makes it easy to	No, only two subdirectories

module ?	access to the results	for image and project
Easy to create new project ?	Yes	Fine
Need ground height estimate ?	Yes, need average ground height	Yes, need min. and max. of ground height
Need ground spacing for DTM in project definition ?	Yes	No

3. Project Information Management

In **SoftPlotter** all the information are kept in the subdirectory for that module. For example the information about the photographs and ground points in the project are kept in the files in the subdirectory named **block**. In this way it is easy to have the information you need, and monitor the status. But in **Socet**, the information are kept in the files in the same subdirectory. So it is not easy to find the information if you are not very familiar with the software. On the other hand, since the **SoftPlotter** has different modules and the information are displayed when any of the modules are opened, so it has not obstruction for user to get this kind of information about the current status of the module.

4. Importing Images

Both software can import different types of images. Since different types of imagery format can be converted to each other, it is not a problem for them to used different format of images. But the way that they use to import images is slightly different. It is interesting that **Socet** can not read **TIFF** images with more than one strip correctly. In **SoftPlotter** the images have to be imported after selection of camera. There is a camera database which must contain at least one camera before the image frames can be read. The exterior orientation parameter can be imported from some different results like **Albany**. In the importing process, all the information about the imported frames are displayed on the information table.

In **Socet** the camera calibration data are stored in different camera data files. Before the image is imported, the camera data file has to been chosen. The exterior orientation

can be imported as one option. The imported images are arranged as separate files. It is not easy to get the information about the imported images. There is a function can be used to group stereo model from the imported images.

Table 3 shows some of the comparison.

Table 3 Comparison on Image Importing

	SoftPlotter	Socet
Import exterior orientation from other triangulation ?	Yes, anytime in the processing	Yes, only when importing the images
Can use multiple camera ?	Yes, can use anyone in the camera database	Yes, choose the camera data file when importing
Can modify camera calibration data ?	Yes, anytime in the camera database	Yes, modifications can be done on the camera file
Display all the frame information ?	Yes, all the information are displayed in a window	No
Easy to import ?	Yes	Fine

5. Camera Calibration Data

In **SoftPlotter** all the camera calibration data are stored in a central camera database that can be used by every project. In the **Block** tool of each project, there is another local camera database which is only valid for this project. The calibration data in the database can be modified at any time.

In **Socet** there is a function that can be used to modify the calibration data. Since the camera calibration data for each camera are stored in a separate file, it is not easy to know the number of camera and the types of camera used in the current project. It is not difficult to modify the content of the camera calibration data using the corresponding function. It has a very good graphical interface for user to locate the fiducial point and input the photo coordinates.

Since **SoftPlotter** uses database to handle the camera calibration data, it is easy for users to manage the data in **SoftPlotter**.

6. Interior Orientation

Both software have very good graphical user interface to do the interior orientation. In **SoftPlotter**, the basic image processing tools like magnification are in the same window as other information. But in **Socet** there is a separate tool window for these basic image processing. The latter is better but more complicated.

In **Socet** the fiducial points can be enabled or disabled by checking on yes or unchecking it. This is very convenient.

7. Ground Measurement

The process used in **Socet** for measuring ground points is very complicated. There is a function that can be used to input all the ground points as control points, tie points and check points. The points can also be added or deleted in the measurement window. Since only two images can be displayed at a time, and it has one cursor for each image, one cursor has to be locked before the measurement can be taken. Although only two images can be displayed at a time, any number of images can be loaded if the point to be measured appears on them. Automatic point measurement can be used.

It is a different story for doing ground measurement in **SoftPlotter**. Relatively it is easy to measure the points. Since the ground point information are stored in a table which can be accessed almost every where, its content can be modified very easily. The ground point information can also be imported from a text file. When measuring the point, up to 6 images can be displayed at them same time. Automatic measurement is also available for both pug and control points. Once the points is measured, the point number is marked on the photograph. Another big advantage for **SoftPlotter** here is that the frame information can be accessed from the ground point measurement window and the triangulation can be performed right after the ground point measurement is done. This makes it really fast between the measurement and test of the triangulation. It almost takes

no time to see the triangulation results after finishing the ground point measurement. Table 4 has some comparisons. Since all the information about the ground points are tabulated, it is easy to check and modify the numbers for each point. In **SoftPlotter** up to 6 images can displayed at the same time. Sometime this can cause memory problem such as memory overflow or segment violation. One reason for this is that probably some previously claimed memories are not released when they are done. Somehow it has some problem with color images. It is very slow when loading a color images even the image is not that big.

Table 4 Comparison in Ground Point Measurement

	SoftPlotter	Socet
User friendly ?	Yes	OK
Efficient ?	Yes, can perform triangulation right away	No
Mark measured points ?	Yes	No
Automatic measurement ?	Yes, for both pug and control points	Yes
Can import ground points ?	Yes	No
Display more than two images ?	Yes	No
Any memory managing problem ?	Yes, memory error for big image (e.g. 160MB)	Not test
Easy to activate or deactivate points ?	Yes	OK
Complicated ?	No	Yes

8. Triangulation

It has no problem to perform triangulation in **SoftPlotter**. The triangulation can be performed either in ground point measurement or from the menu in **Block** tool. The result of triangulation can be viewed right after the triangulation is done, no matter the results

are good or not. All the information about the triangulation are stored in a text file which can be easily accessed.

The same good data used in **SoftPlotter** are tried in **Socet**, and the triangulation is not available.

9. Summary

All the operations in **SoftPlotter** are easy to handle. It is very user friendly. But the same operation in **Socet** may be very complicated. But as a softcopy photogrammetry software package, **Socet** has more functions than **SoftPlotter** has. Probably **Socet** can produce better results or the kind of result that users need. But for general purpose, **SoftPlotter** is good enough.

There are some other things like DEM editing, 3D digitizing and printing that can be compared. Since there is not enough experience on **Socet**, the comparison is not available right now.

Performance comparison of TNTMips and Softplotter in
generating DEM and Orthoimages for crop yield mapping and
modeling

Project Report

Major Professor: Dr. Jeyapalan

Vijayanand Sumangali

November 2, 1997

Contents

1	An overview of TNTMips5.6 and Softplotter1.6	2
1.1	TNTMips	2
1.2	Softplotter 1.6	3
2	Results from GRID	4
3	RESULTS AND CONCLUSIONS	8
3.1	Differences between TNTmips and Softplotter	8
4	Orthophoto and DEM Quality	10
5	Results from GRID	10
6	Drawbacks and ways to overcome them	11
7	TNTmips or Softplotter	11

List of Figures

1	TNTmips DEM and Contours in GRID	5
2	Planimetric Map of Larson by mips	6
3	Planimetric Map of Larson by softplotter	7

1 An overview of TNTMips5.6 and Softplotter1.6

1.1 TNTMips

A powerful and spatial analysis package developed by Microimages Inc, A Nebraska based firm. It has the capability of dealing with both raster and vector based data and its very user friendly when compared with some of the other commercial GIS software in the market. It also has the ability to generate Orthophoto and DEM models for Spot imagery and aerial photographs with the stereoscopic modeling tool.

The user interface for this tool has been modified and improved over the years and has been getting better and better with every upgrade. The process for orthoimage generation using this package is essentially divided into the following major steps listed as follows :

- The aerial photographs for the area under study are scanned and stored in an Image format and is imported into TNTMips as a raster to enable the usage of the data by the software.
- The raster obtained from the left aerial photograph is assigned horizontal and vertical control by identifying control points in the photograph whose positional and elevation information are known. This is important before moving onto the stereoscopic modeling process. Absence of this information will not get us any further. This software does not require the user to assign control to the raster obtained from the right photograph.
- The position of the principal point for the raster pair is computed using the raster examination tool. This data alongwith the camera data is required for the interior orientation module, the first step in the stereoscopic modeling tool.
- The prospective projection process follows the interior orientation step. This step generates an epipolar stereo-pair by resampling the raster images which are assigned tiepoints in this process. Tiepoints are points in the model area or the area common to both the photographs. Points which are found to be similar in both the photographs are chosen to be tiepoints.
- The epipolar raster pair generated is now ready to be used for DEM generation which is the next and penultimate step in the stereoscopic modeling process. The DEM process uses the tiepoints created earlier to autogenerate many more tiepoints covering the entire model area in order to get a dense DEM representing the model area on the whole without any holes. This process uses the TIN densification algorithm to generate the DEM. The parameters involved in the autogenerate process can always be changed to meet the needs of the user. This process can be repeated till the output DEM generated is satisfactory. The raster examination tool can be used to check the elevations at various points in the DEM.

- The orthophoto generation process culminates the steps involved in the stereo modeling tool and uses the resampled epipolar image obtained from either the left or the right photograph and the DEM generated from the raster pair to generate an orthoimage. The parameters involved can be tested to verify the values before initiating the process.

1.2 Softplotter 1.6

Softplotter 1.6 developed by Vision International is a fully functional Soft Photogrammetric software used to generate stereo-pairs, DEMs and Orthoimages. In addition, this software can also be used to develop aerial mosaics / strip. The software needs to be installed / configured on powerful Unix based workstations with high end graphics display and resolution like the SGI's and Suns.

Some accessories like the special 3-D mouse, Crystal LCD indicator to enable stereo-viewing, stereo glasses and an additional monitor come along with the software to fully harness its potential. Some level of skill is required to use this software in order to generate Orthoimages and other products. Some knowledge of operating system with reference to file management and such related tasks will also be needed. This software like TNTmips follows a set of procedures before generating the DEM and the Orthophoto. The steps are shown as follows:

- The first step is the creation of a new project directory which will store all the required files to be used by the software during the ortho generation processes. If a project has already been started, the user can begin with an already existing project directory.
- Next step is the block editor which is like the building block for this software. The user cannot proceed further before satisfying conditions in this process.
 - 1) Select the camera from the camera editor used to take the photographs. This information is important to compute the parameters for the interior orientation. The camera data needs to be added for use in this project if its not available in the database.
 - 2) The next step would be the entry of the coordinates of the eight fiducial marks for the photograph. Then the photographs are taken to the frame editor. This module has the capability to deal with upto three stereo-pairs at a time. The photographs which are stored in an image format for scanning will now be imported into the frame editor for further use. Unlike TNTmips, the photographs need not be converted into rasters.
 - 3) Now the control points and the tiepoints are added to the frame editor. The controls are assigned horizontal or vertical control based on the accuracy of their known coordinates. Atleast three control points are needed to perform the triangulation process.
 - 4) As the triangulation process runs error free, the stereoimage can be generated by accepting the triangulation results. If there is an error during the triangulation, the

report generated for the process can be used to correct or delete any bad points which might be inducing the error.

- The stereoimage obtained from the triangulation can be used to make the measurements in the model area which gives a fair idea about the terrain in general with the elevation at any desired location in the model area. This is very useful to check for anomalies in elevation. This feature gives softplotter an edge over TNTmips.
- The next step in the process would be the DEM tool which will use the stereoimage as its input from the frame and will generate the DEM for the model area. The DEM created is in a raster format. The surface tool can be used to edit the DEM or convert the DEM to the TIN which can be edited using the KDMS tool.
- The ortho tool used to generate the Orthoimage. It expects one of the photographs and the DEM of the model area as the input. The final orthoimage is stored in the project file in the TIFF format and it is ready to be used by a GIS along with its transformation information file which has a (.TFW) suffix.

There are other tools available like the mosaic tool aiding the formation of a strip from adjacent model areas and the imagine tool which can analyze and give Softplotter raster based GIS processing capabilities.

2 Results from GRID

The DEM from TNTmips and Softplotter were generated with a cell size of 0.45m for comparison purposes. A difference DEM was created to study the difference between the two DEMs. The mean difference between the two DEMs was about 0.3m. Interestingly enough, while the DEM generated by TNTmips was smooth with gradual elevation difference, the softplotter generated DEM was very speckled with significant elevation differences in a very small area. Figure 1 shows the DEM generated by TNTmips and the contours.

The softplotter DEM was reexamined and it was observed that it had way too many points in a small area and due to limitation in the number of points taken by the tin, could go no further. However, when the cell size of the resulting DEM was changed to 5.0m from 0.45m, softplotter generated a DEM which was very smooth and comparable with the TNTmips DEM.

The control point information was overlayed over both the orthoimages and the errors in the placement of the points was computed using the *length* command and the arcview *distance* command. The results obtained from the overlay were as follows:-

• **Mips Orthoimage:-** The error in the placement of control points with ids 12, 45, 69 and 71 were found out to be 1.95m, 2.34m, 1.86m, 1.36m respectively. Some other measurements were taken from some linear features in the model area like the railway track at various places and the gravel road. The width of the railway gauge as measured on the mips ortho

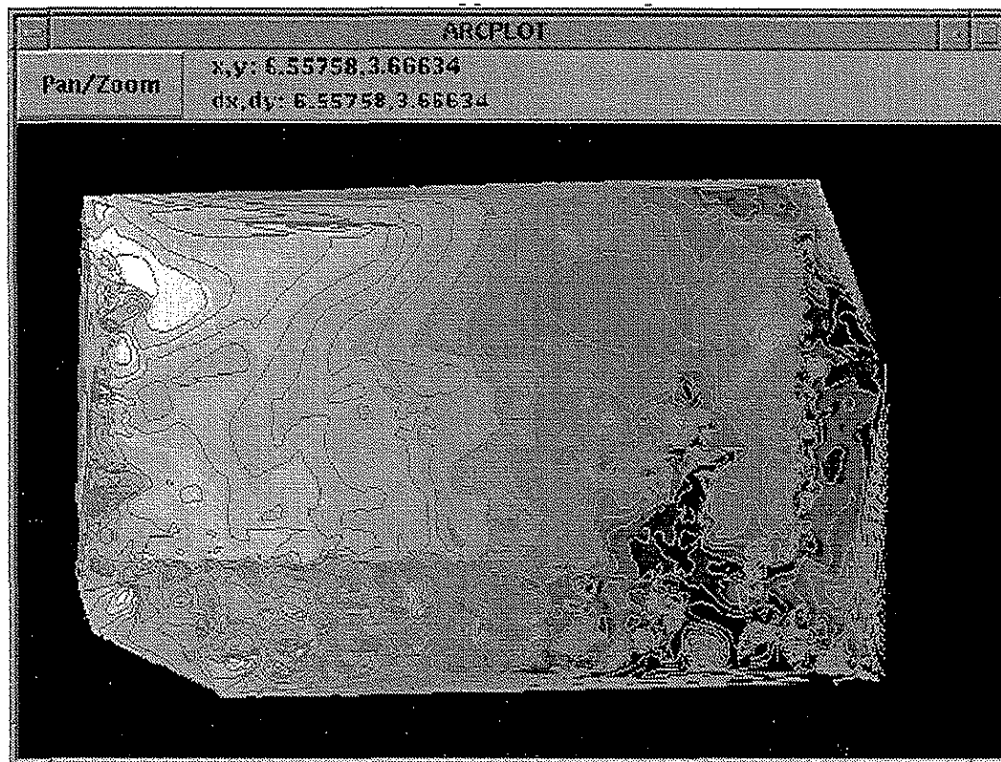


Figure 1: TNTmips DEM and Contours in GRID

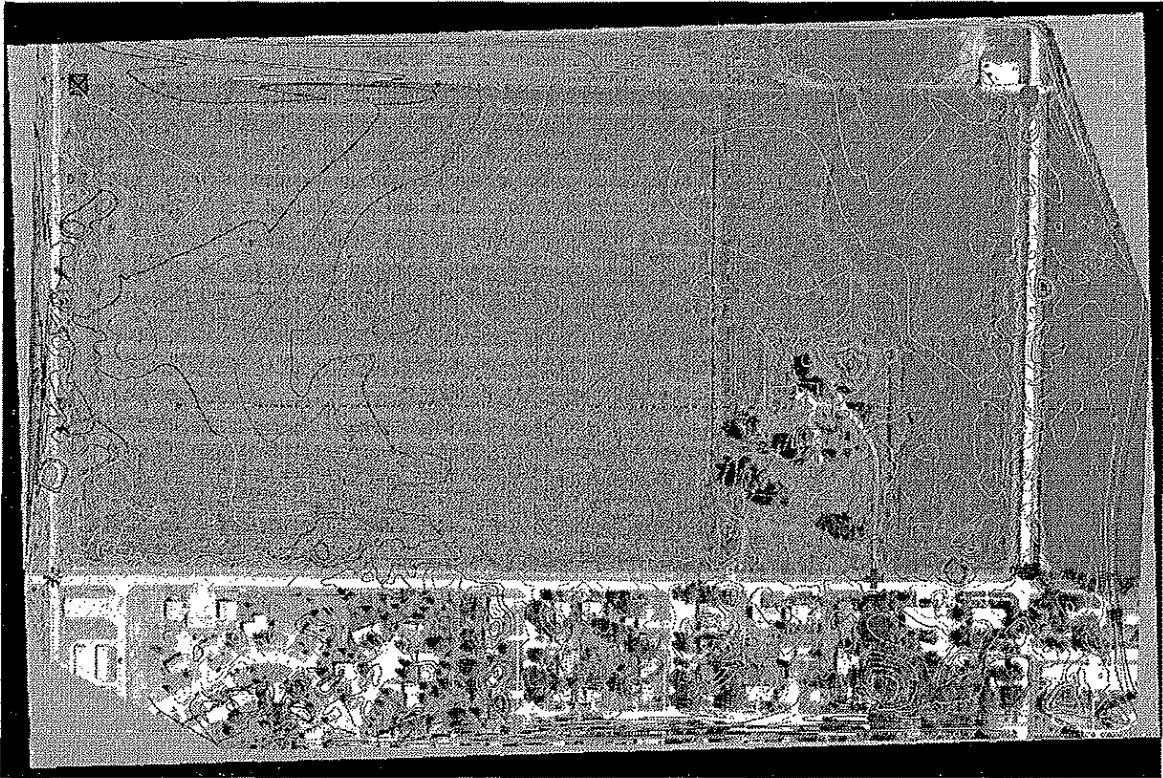
was found to be 1.52m where as the standard guage width is 4 feet 8.5 inches or 1.435m. The road was found to be 7.44m wide which is about 24.49 feet. The planimetric map of Larson created by the mips based products is shown in Figure 2.

•**Softplotter Orthoimage:-** The error in the placement of the control points with ids 12, 45, 69 and 71 were found out to be 1.5m, 1.70m, 2.41m, 1.43m respectively. The measurement taken on the railway track resulted in the width of the guage being reported as 1.47m when compared with the standard guage of 4 feet 8.5 inches. The width of the gravel road was measured as 7.42m or 24.31 feet.

Figure 3 displays the planimetric map generated with the softplotter products.

Control point information is so important to check the accuracy of orthophotos and DEMs and this project provides us with information about four points encompassing the model area. There were about 71 points whose coordinate information was available through GPS for the model area and we were able to use only four. The implications of these results on the orthoimage and the DEM quality will be given comprehensive treatment in the concluding chapter. Suggestions and scope for future work will also be discussed.

Planimetric Map of Larson by TNTmips

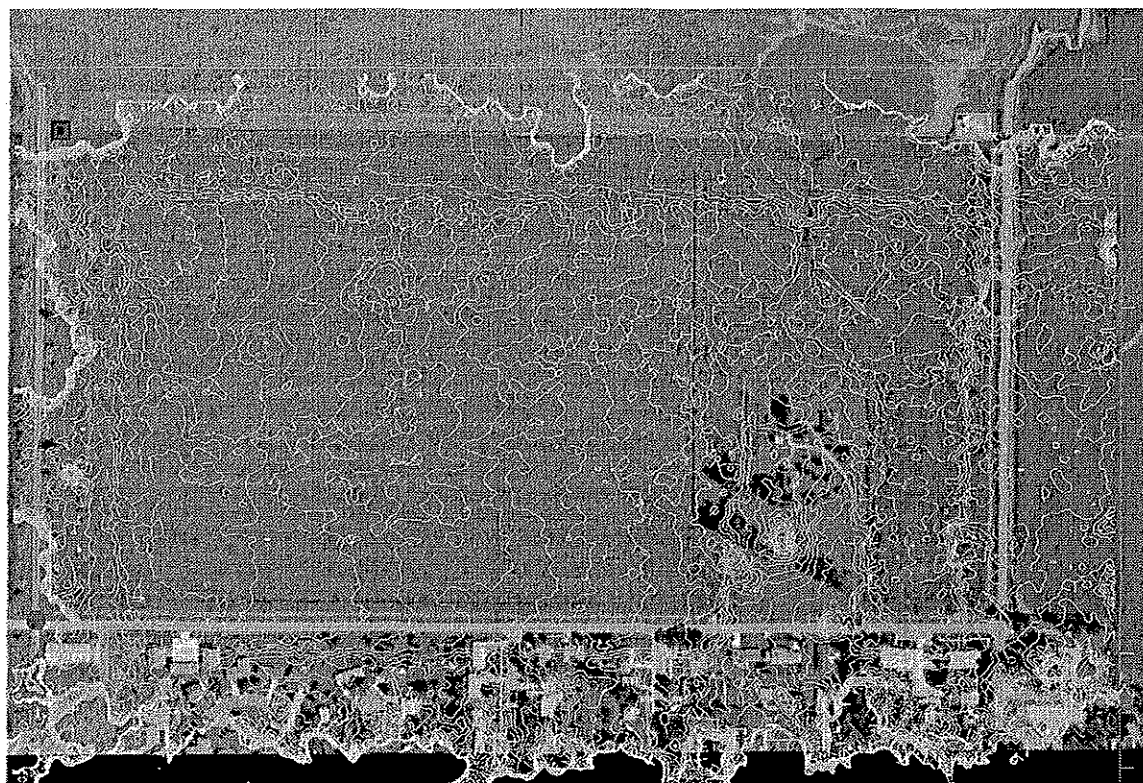
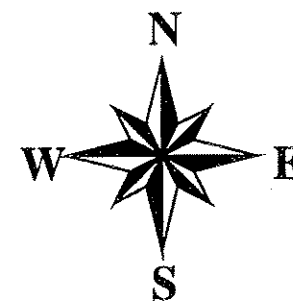


- Mipsctr
- 277
 - 277.5
 - 278
 - 278.5
 - 279
 - 279.5
 - 280
 - 280.5
 - 281
 - 281.5
 - 282
 - 282.5
 - 283
 - 283.5
 - 284
 - 284.5
 - 285
 - 285.5
 - 286
 - 286.5
 - 287
 - 287.5
- Control
- * 12
 - 45
 - 69
 - 71



Figure 2: Planimetric Map of Larson by mips

Planimetric Map of Larson from Softplotter



	Modcntr
Control	
●	12
■	45
+	69
*	71



Figure 3: Planimetric Map of Larson by softplotter

3 RESULTS AND CONCLUSIONS

It has been observed that TNTmips and softplotter have different methodologies for the creation of orthoimages and elevation models from aerial photographs. The differences in the approach of both the software are discussed below. This will be followed by an assessment of the quality of orthoimages and DEM for Larson generated by these software and will culminate with conclusions and recommendations for further work.

3.1 Differences between TNTmips and Softplotter

The differences between these software is best explained by elaborating on the following issues:-

- **Pre triangulation procedures:-** Both software expect different parameters as input for the interior orientation process. While TNTmips expects the camera focal length, scanner resolution and position of the principal point as inputs, *softplotter* needs the camera data which includes the coordinates of the fiducial marks. The presence of a camera database in softplotter helps in using the data for multiple projects without having to re-enter things again.

Softplotter is better equipped to deal with the interior orientation process as it computes the position of the principal point based on the coordinates of all the available fiducials where as TNT has to calculate the position of the principal point based on the coordinates of the center fiducials which are not available most of the time due scanner limitations.

Interior orientation is followed by relative orientation where the control point information and the tie point information are assigned to the photographs in order to get them ready for triangulation. For softplotter, the frame editor is used to add control points and tiepoints to both left and right images. The control points can be added simultaneously to both the photographs and the auto correlation tool is used for adding tiepoints. TNT uses two tools for relative orientation process, one being the georeference option to add control information and the other being the relative orientation. The right photograph need not be assigned control point information in this case.

The main limitation of mips here is the inability of its auto correlation tool to work on 24 bit color images. The photographs have to be essentially 8 bit gray scale rasters to be used. While softplotter has no limits set on the number of tiepoints to be added, TNT requires a minimum of 10-15 tiepoints to get reasonable results. While a user can only work on one stereopair at a time in TNTmips, the frame editor of softplotter enables the user to work on three stereopairs simultaneously which gives it the edge for performing triangulation of strips encompassing large areas.

- **Triangulation and Stereomodel:-**Softplotter also provides a detailed triangulation process report which can be readily used to rectify or remove a bad tie point or a control point. This results in the production of a better stereo model which can be used for making some measurements and to generate a DEM. TNT does not provide a comprehensive orientation report and the only way to determine bad points is by using the color coded correlation coefficient as a touchstone. The presence of larger gray areas might result in an improper correlation. Softplotter has a very good stereotool which can be used to take some elevation measurements from the stereomodel and can also be used as an editing tool later to remove bad points in the DEM. TNT does have a stereotool which is more in the evolving stages.
- **DEM Generation and Orthorectification:-**Softplotter can generate the DEM from either the DEM tool or the surface tool. The automatic collection algorithm is excellent as it collects points in the model area based on the ground distance specified. In contrast, the DEM extraction tool of TNTmips works on a combination of manual and automatic tie point collection system. Different techniques have to be adopted to force the process to add some points in some gray areas and regions with insufficient control.
The orthorectification process in both the software work on similar lines with the softplotter ortho tool provides additional options of producing orthophotos from TINs.
- **Performance and other general features:-** Softplotter is made available only as a stand alone Unix system where as TNTmips is available in Unix and Windows as well. The softplotter hardware which comprises of high end graphics display, CPU and the special stereo glasses and mouse for stereoviewing and editing costs a lot more than the TNTmips software and its hardware which run into a few thousand dollars. The system performance of both software is almost comparable. The only limitation with mips being that it might take more time to process real huge and complex datasets. With the automation in TNTmips not being total, the amount of time taken by it to produce results is greater than that taken by softplotter.
- **Data Structure and Flexibility:-** Softplotter uses a project directory and stores all the components in various sub-directories. TNTmips stores everything related to a project in a project (.rvc) file.
TNT with its GIS capabilities offers greater data flexibility than softplotter. The data in TNTmips can be converted to a lot of industry standard formats and vice-versa. In contrast the softplotter data can be converted and used by very few other software.

Both software dont have a cell based or raster based modeling system at their disposal and have to depend on a third party GIS software like ARC/INFO for such needs. However the software do have some image processing capabilities with softplotter depending on ERDAS Imagine for this functionality whereas these features are inbuilt for mips.

4 Orthophoto and DEM Quality

The results obtained from the analysis using GRID is significant as it provides an insight into the issues of product betterment and quality control for the orthoimages and DEMs. Quality of an orthoimage falls into two categories, one being spatial accuracy and the other being image quality. Spatial accuracy is concerned with the location of the pixel elements in reference to their true location. Image quality is associated with the defects and tonal differences and the radiometric corrections which might be necessary.

Orthophoto basemaps have excellent horizontal accuracy when compared with the conventional line and symbol maps. The National map accuracy standards specifies the following conditions for horizontal accuracy: For maps on publication scales larger than 1 : 20,000, not more than 10 measured on publication scale. For maps on publication scales of 1 : 20,000 or smaller, it is 1/50 inch. These limits apply to well defined points only.

With orthophoto pixel size being less than half a meter, the quality of the image suggests a higher accuracy than what the image can support. The factors which affect spatial accuracy are many and the DEM is among the prominent ones. DEMs are often collected in a systematic grid where points collected in this fashion are called the mass points. While this results in meeting some requisite accuracy standards, collecting additional points and lines might result in a better DEM which is of much more utility to the GIS user. The DEM should thus always be a collection of masspoints, breaklines and significant points.

5 Results from GRID

As seen in the previous chapter, the four known control points were used to test the accuracy of the two orthoimages generated by TNTmips and Softplotter respectively. The average error in measurement for the control points was found to be 1.76m for Softplotter and about 1.88m for TNTmips.

The map scale for both these orthoimages which were derived from aerial photographs taken from a height of about 3500 feet is 1(inch): 596(feet). Based on the national map accuracy standards, atleast 10 of the measured points should report an error of less than 0.02 inches. The points which reported the maximum placement error for both the images were tested and they were found to have an error of less than 1/50th of an inch.

This implies that all the points measured meet the national map accuracy standards without any problem. Some measurements were conducted on some prominent linear features in the images like the width of the rail gauge and both the images came within 11-15cm of the actual measurement. This is equal to half the cell size of these raster images which shows the limitation of the grid.

A close look at some of these results suggest that the orthoimages produced by Softplotter and TNTmips are of very good quality with respect to spatial accuracy. The image quality is very high as the images were scanned at 600 dots per inch. The only quality reducing factors here are the deep shadows caused by low sun angles.

6 Drawbacks and ways to overcome them

Although the accuracy of the final orthoimages and DEM generated by both the software are very satisfactory, the main drawback for this project was the insufficient control point information. The model area had the coordinates of 71 points from GPS and unfortunately only four of them could be used as the positions of the remaining points on the photograph could not be determined even fairly.

This shows how invaluable good targets can be to any mapping project. Having good targets as control points gives more options and makes the user better equipped to exactly verify the quality of the final orthoimage and DEM as was the case with the *treynor* project. The treynor watershed project had well defined 5 feet targets on the ground for which GPS data was collected. The images were rectified and the DEMs were built using TNTmips resulting in very good orthoimage and DEM.

For future mapping purposes concerning this project area, the research suggests setting up some good ground targets by surveying in order to obtain better control information for the model area.

7 TNTmips or Softplotter

One of the prime objectives of this research was to evaluate the performance of TNTmips as a photogrammetric software and to determine the quality of the products it produced namely the DEM and the orthophoto.

This research suggests that TNTmips which is really inexpensive when compared with the softcopy photogrammetry software like softplotter, does a fine job with stereoscopic modeling. This result however should not evince conclusions like why do we need a state of the art, expensive softcopy photogrammetry software like Softplotter when we have something simple and inexpensive like TNTmips.

This is because we have had very less to compare as far as the data dealt with is concerned. Photogrammetry projects are much more complex covering bigger areas than the one in this project. These projects involve intense computations where the model area or strip comprises of more than 10 photographs or five stereopairs where all the models will be mosaicked after triangulation and rectification.

The key to Softplotter lies in its ability to perform simultaneous bundle block adjustment for triangulation where the user can work on three different stereopairs or up to six frames at a time. A superior stereoviewing tool gives a good perspective of the model area and enables the user to take measurements. Good point collection algorithm collects points for the DEM from areas with least control.

The gist is that Softplotter is a fully commercial productional photogrammetry package while TNTmips within its restrictions is good for smaller projects such as this research. This research concludes by suggesting that TNTmips can be used effectively to deal with projects of smaller magnitude.

Appendix D

Transfer of Technology

OFFICE OF THE
MILLS COUNTY ENGINEER

418 Sharp Street
Glenwood, Iowa 51534

Telephone (712) 527-4873
FAX (712) 527-5124

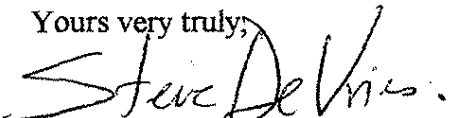
July 1, 1997

Dr. K. Jeyapalan
College of Engineering
Department of Civil and Constructing Engineering
Iowa State University
Ames, Iowa 50011-3232

Dear: Dr. Jeyapalan:

I looked over the information you sent me regarding conversion of highway video logs into 3D coordinates via soft photogrammetry. This appears to be a technology application that could be of significant benefit to the road and highway administration business. I encourage you to pursue it and perfect it -- perhaps demonstrating how to develop a representative plan and profile from a mile of roadway. Please keep me updated as to your future progress. Thanks.

Yours very truly,


Stephen W. DeVries, P. E.

dct97jul01dct.sam

Stephen W. DeVries, P.E.
County Engineer

Nancy Clayton
Office Manager

Evan Wickham
Engineering Assistant

James L. Petty, L.S.
Engineering Assistant

Apr. 17, 1997

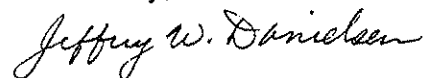
Jeffrey W Danielsen
Iowa Dept. of Trans.
800 Lincolnway
Ames, Iowa 50010

Dr. Kandiah Jeyapalan
Professor of Photogrammetry
Room 428 Town Engineering
Iowa State University
Ames, Iowa 50011

Dear Dr. Jeyapalan,

In response to your request for comments on our work with Softplotter, I am enclosing a short report . I would like to thank you and Yao for allowing me to participate in this research. I appreciate the time and energy spent, and extend my apologies for not getting this to you sooner. If you have no objections I will use some of the time spent as professional development hours for my continuing education requirement for my land surveyors license. Please feel free to call me at 239-1979 or visit with me if you have any questions or comments.

Sincerely,



Jeffrey W. Danielsen
Design Technician
Photogrammetry
Iowa Dept. of Trans.

I was involved with the study of the Vision International Softplotter at the Town Engineering building at Iowa State University on March 11 & 10, 1997. I participated with the three-dimensional mapping.

I am employed as a stereoplotter operator on a Kern PG-2 analog stereoplotter. This report is based only on my opinion and the comparison of the softplotter to the analog plotter.

The stereo image, which was available with the softplotter, was not visually clear, therefore it was hard to distinguish ground elevations and features, such as shaded areas around trees and dark areas like plowed fields. With the analog plotter using diapositives the image is sharper and visually clearer. This might be resolved with scans with a higher quality scanner at a higher resolution, or by scanning a photo opposed to a diapositive which was used in this case.

I was not involved with the set up of the models but see a significant time savings compared to the set uptime of an analog plotter.

The hard drive space that is required with softplotter is significantly larger, to store the scanned images.

There was only one monitor operating at the time so the actual work area on the screen was small, due to all the menus and views on one screen. I feel that a double monitor is a must for a larger viewing/working area with the softplotter .

The 'crystal eyes' glasses were very uncomfortable on my nose, I wear prescription glasses and that might contribute to that discomfort. Viewing things other than the stereo model with the glasses would take some getting used to. The upright seated position with the softplotter compared to forward leaning position with the analog is much more comfortable. With the softplotter there is less neck motion with everything directly in front of you, which I found to be less stressful on my neck, compared to having to look up and down from the analog plotter to the computer monitor and back numerous times during the process. Using the 3D cursor/digitizer with the softplotter was comfortable and similar to the 3D cursor on the analog plotter with the exception of the control buttons being located on the softplotter cursor and with the analog plotter the computer mouse is separate.

A comparison was made of the topography file I created at I.S.U. and the file previously created as part of the Iowa D.O.T. project and the features lined up very well.

The time I spent working with the softplotter was brief and some of my opinions may be different with prolonged use of the plotter as with anything. I do want to thank you for letting me participate in this study and giving me the chance to have the hands on experience.

Jean Borton
Design Tech IV
Photogrammetry
Iowa Department of Transportation

COMMENTS ON VISION INTERNATIONAL SOFTPLOTTER PHOTOGRAMMETRIC SYSTEM

In early March of 1997, I was invited by Dr. Jeyapalan, professor of photogrammetry at Iowa State University, to observe and participate in a demonstration of a softcopy photogrammetric system at the Town engineering building on the I.S.U. campus. The system, Vision International Softplotter, runs in a windows based platform on a dual screen Silicon Graphics unix workstation. From a analytical stereoplotter operator's view, I have made some observations regarding aerial triangulation, digital elevation models, ortho-photo production, digital mapping, and various aspects of this softcopy photogrammetric system.

Running in a windows environment, the software modules or tools seem to be arranged in a logical manner. They include: 1. Production Management tool for file creation, import and export of digital images, and manipulation of data. 2. Block tool for aerial triangulation. 3. Stereo tool for viewing digital images. 4. DEM tool for digital elevation models. 5. Surface tool for extracting the TIN model. 6. Ortho tool for rectifying the images. 7. Mosaic tool. 8. Mensuration tool. 9. Kork digital mapping tool. 10. DGN tool. 11. Geo Catalogue tool.

When performing interior orientation of the digital images, I was concerned about the high residual values from Softplotter. Typically my readings with Softplotter were averaging 20 to 30 microns, with some fiducials reading as much as 80 to 90 microns. On the Zeiss analytical plotter we can generally obtain 2 to 10 micron accuracy with 20 microns as the high tolerance level. The quality of the scanned images as well as inexperience of the operator, myself, most likely play a big role in the higher residuals. The operation of measuring the fiducials and storage of camera data was fairly straightforward. Being able to adjust the brightness and contrast of the digital images is a definite advantage over traditional diapositives, provided the images are scanned at a high enough resolution. Unless the image files are compressed or zipped, the file size of those images scanned at higher resolution become very large, creating an increased time and space factor for handling large strips of models.

The measuring of points for the exterior orientation of the images is done on the left image in 'mono' and then 'matched' to the right image. Some difficulties were encountered in 'matching' pre-marked pass points, due partially to areas of plowing or cultivation with no distinctive shapes or features to identify a 'close area' for matching on the right image. Results would surely differ if clusters of non-marked points scattered over more area were used to bridge the images.

Autometrics triangulation program seems to provide a very rapid and rigorous solution. Being accustomed to using dos based Albany outside of windows, I felt that softplotter's triangulation package was much more 'user friendly'. My limited experience with measuring points and the softplotter system in general left my triangulation results somewhat shaky. I am confident that with more time spent they would have improved vastly.

Yao , an experienced softplotter operator has proven that results obtained from the system fit very closely to our Albany triangulation results.

Stereoviewing of the digital images is done with 'crystal eyes'. I had no problems in viewing the models in stereo, however, viewing other data and computer operations with the glasses on would take some getting used to.

On a previous visit I had the opportunity to view DEM compilation and results. Confidence levels of points and features is a plus in softplotter. One disadvantage to auto-correlation in the DEM is man made features, trees, buildings, etc. are not distinguished by the system and must be edited. A great advantage of auto-correlation is time saved by softplotter verses time spent in semi-manual compilation of DEM on the analytical stereoplotter.

The digital ortho-photo and mosaicking capabilities of softplotter would provide great benefit to us at the Dept. of Transportation for public displays, corridor location, design, and other uses.

Three dimensional mapping on softplotter is done with the Kork digital mapping system. Using the 3D cursor/digitizer was comfortable for moving around and gathering planimetric detail. I personally did not feel as confident gathering topographic information due to my inability to see clearly certain features to be plotted. Here again, in my opinion, the quality of the film and the resolution of the scanning, combined with the scale of the photography can make a big difference.

Having spent a relatively short time with Vision International's Softplotter I got the overall impression that it works fairly smoothly at doing what it is designed to do. It is my understanding that most softcopy photogrammetry users are going to NT based systems over Unix. I would assume that like the other softcopy software producers Vision International would head in that same direction. There is no doubt in my mind that eventually softcopy photogrammetry is going to replace analogue and analytical stereoplotters in the future. I wish to thank Dr. Jeyapalan, Yao, and the I.D.O.T. for allowing me to participate in this new technology.

Jeffrey Daniels
Design technician photogrammetry
Iowa Dept. of Transportation